

Engineering Thermodynamics

en.wikibooks.org

April 11, 2015

On the 28th of April 2012 the contents of the English as well as German Wikibooks and Wikipedia projects were licensed under Creative Commons Attribution-ShareAlike 3.0 Unported license. A URI to this license is given in the list of figures on page 65. If this document is a derived work from the contents of one of these projects and the content was still licensed by the project under this license at the time of derivation this document has to be licensed under the same, a similar or a compatible license, as stated in section 4b of the license. The list of contributors is included in chapter Contributors on page 63. The licenses GPL, LGPL and GFDL are included in chapter Licenses on page 69, since this book and/or parts of it may or may not be licensed under one or more of these licenses, and thus require inclusion of these licenses. The licenses of the figures are given in the list of figures on page 65. This PDF was generated by the $\text{\LaTeX}$ typesetting software. The $\text{\LaTeX}$ source code is included as an attachment (`source.7z.txt`) in this PDF file. To extract the source from the PDF file, you can use the `pdfdetach` tool including in the `poppler` suite, or the <http://www.pdfabs.com/tools/pdftk-the-pdf-toolkit/> utility. Some PDF viewers may also let you save the attachment to a file. After extracting it from the PDF file you have to rename it to `source.7z`. To uncompress the resulting archive we recommend the use of <http://www.7-zip.org/>. The $\text{\LaTeX}$ source itself was generated by a program written by Dirk Hünninger, which is freely available under an open source license from http://de.wikibooks.org/wiki/Benutzer:Dirk_Huenniger/wb2pdf.

Contents

1	Preface	3
2	Introduction	5
2.1	Introduction to Classical Thermodynamics	5
3	Thermodynamic Systems	9
3.1	Properties of Pure Substances	9
3.2	Thermodynamic Systems	10
3.3	Zeroth Law of Thermodynamics	12
3.4	Temperature Measurement	12
3.5	The Ideal Gas	13
4	Zeroth Law	17
5	First Law	19
5.1	Energy	19
5.2	Work	19
5.3	Heat	22
5.4	First Law of Thermodynamics	24
5.5	Statement of the First Law for a Closed System	25
5.6	Enthalpy	27
6	Second Law	29
6.1	Introduction	29
6.2	Introduction	29
6.3	Statement of the Second Law of Thermodynamics	29
6.4	Carnot Cycle	31
6.5	Thermodynamic Temperature Scale	32
6.6	Statement of the Second Law of Thermodynamics	33
6.7	Carnot Cycle	34
6.8	Thermodynamic Temperature Scale	36
6.9	NOTE	37
6.10	Clausius Theorem	37
6.11	Entropy	38
6.12	Availability	41
7	Third Law	43
7.1	Third Law of Thermodynamics	43
8	Applications	45
8.1	One Component Systems	45

8.2 Psychrometry	48
8.3 Common Thermodynamic Cycles	52
9 Further Reading	61
10 Contributors	63
List of Figures	65
11 Licenses	69
11.1 GNU GENERAL PUBLIC LICENSE	69
11.2 GNU Free Documentation License	70
11.3 GNU Lesser General Public License	71

1 Preface

The topic of thermodynamics is taught in Physics and Chemistry courses as part of the regular curriculum. This book deals with Engineering Thermodynamics, where concepts of thermodynamics are used to solve engineering problems. Engineers use thermodynamics to calculate the fuel efficiency of engines, and to find ways to make more efficient systems, be they rockets, refineries, or nuclear reactors. One aspect of "engineering" in the title is that a lot of the data used is empirical (*e.g.* steam tables), since you won't find clean algebraic equations of state for many common working substances. Thermodynamics is the science that deals with transfer of heat and work. Engineering thermodynamics develops the theory and techniques required to use empirical thermodynamic data effectively. However, with the advent of computers most of these techniques are transparent to the engineer, and instead of looking data up in tables, computer applications can be queried to retrieve the required values and use them in calculations. There are even applications which are tailored to specific areas which will give answers for common design situations. But thorough understanding will only come with knowledge of underlying principles, and the ability to judge the limitations of empirical data is perhaps the most important gain from such knowledge.

This book is a work in progress. It is hoped that as it matures, it will be more up to date than the dead tree editions.

Thermodynamics is the study of the relationships between HEAT (thermos) and WORK (dynamics). Thus, it deals with energy interactions in physical systems. Classical thermodynamics can be stated in four laws called the zeroth, first, second, and third laws respectively. The *laws* of thermodynamics are empirical, *i.e.* , they are deduced from experience, and supported by a large body of experimental evidence.

The first chapter is an introduction to thermodynamics, and presents the motivation and scope of the topic. The second chapter, Thermodynamic Systems¹, defines some basic terms which are used throughout the book. In particular, the concepts of system and processes are discussed. The zeroth law is stated and the concept of temperature is developed. The next chapter, First Law², develops ideas required for the statement of the first law of thermodynamics. Second Law³ deals with heat engines and the concept of entropy. Applications⁴ of the tools developed in the previous chapters are illustrated, including the use of thermodynamics in everyday engineering situations. Appendix⁵ gives a list of tables for some commonly used properties.

1 Chapter 2.1.1 on page 7

2 Chapter 4 on page 17

3 Chapter 5.6.1 on page 28

4 Chapter 7.1 on page 43

5 <http://en.wikibooks.org/wiki/Engineering%20Thermodynamics%2FAppendix>

This course forms the foundation for the Heat Transfer⁶ course, where the *rate* and mechanisms of transmission of energy in the form of heat is studied. The concepts will be used in further courses in heat, Internal Combustion Engines⁷, Refrigeration and Air Conditioning⁸, and Turbomachines⁹ to name a few.

Category:Engineering_Thermodynamics¹⁰

6 <http://en.wikibooks.org/wiki/Heat%20Transfer>
7 <http://en.wikibooks.org/wiki/Internal%20Combustion%20Engines>
8 <http://en.wikibooks.org/wiki/Refrigeration%20and%20Air%20Conditioning>
9 <http://en.wikibooks.org/wiki/Turbomachines>
10 http://en.wikibooks.org/wiki/Category%3AEngineering_Thermodynamics

2 Introduction

2.1 Introduction to Classical Thermodynamics

Thermodynamics is the study of energies. More specifically, introductory thermodynamics is the study of energy transfer in systems. Classical thermodynamics consists of methods and constructs that are used to “account” for macroscopic energy transfer. In fact, energy accounting is an appropriate synonym for classical thermodynamics. In much the same way that accountants balance money in and money out of a bank account, rocket scientists simply balance the energy in and out of a rocket engine. Of course just as a bank account’s balance is obfuscated by arcane devices such as interest rates and currency exchange, so too is thermodynamics clouded with seemingly difficult concepts such as irreversibility and enthalpy. But, also just like accounting, a careful review of the rules suggests a coherent strategy for maintaining tabs on a particular account.

If a statement about the simplicity of thermodynamics failed to convert would-be students, they may be captured with a few words on the importance of understanding energy transfer in our society. Up until about 150 years ago or so, the earth’s economy was primarily fueled by carbohydrates. That is to say, humans got stuff done by converting food, through a biological process, to fuel we could spend to do work (e.g. raise barns). This was a hindrance to getting things accomplished, because it turned out that most of that energy went to growing and cultivating more carbohydrates (e.g. crops and livestock). We won’t even talk about how much food the horses ate!

Today, we have the luxury, primarily through an understanding of energy, to concentrate our energy production into efficient low maintenance operations. Massive power plants transfer energy to power tools for raising barns. Extremely efficient rocket engines tame and direct massive amounts of energy to blast TV satellites into orbit. This improvement in energy mastery frees humanity’s time to engage in more worthwhile activities such as watching cable TV. Although most are content to blissfully ignore the intricacies that command their way of life, I challenge you to embrace the contrary.

By no means is the energy battle over. Understanding energy transfer and energy systems is the second step to overcoming the limits to what humanity can accomplish. The first step is commanding an interest in doing so from an inclined portion of the population. Given the reader (and editor) has read this far through this aggrandizing rhetoric, I welcome your interest and hope to see it continue until the end.

2.1.1 The Main Macroscopic Forms of Energy

It will be in the best interest of the reader to have defined energy before it is discussed further. There are three primary forms of energy that are discussed in macroscopic ther-

modynamics. Several other forms of energy exist, but they generally exist on a microscopic level and should be deferred to more advanced study.

Kinetic Energy

The first form (probably most easily understood idea of energy) is defined by the motion of an object. Kinetic energy is the energy of a moving mass. For instance, a moving car will have more kinetic energy than a stationary car. The same car traveling at 60 km/h has more kinetic energy than it does traveling at 30 km/h.

$$\text{Kinetic Energy} = (1/2) \times (\text{mass}) \times (\text{velocity})^2$$

$$\text{Ratio of } v_{60}^2 / v_{30}^2 = ((60)(1,000 \text{ meters/sec})(3600 \text{ sec/hour}))^2 / ((30)(1,000 \text{ meters/sec})(3,600 \text{ sec/hour}))^2$$

So, once the algebra is completed properly we find the vehicle traveling at 60 km/h has four times the kinetic energy as when it is traveling at 30 km/h, while the vehicle has zero kinetic energy when it is stationary because the velocity = zero(0) results in $1/2mv^2$ ($1/2 \times m \times 0 = 0$) being zero.

Potential Energy

The second type of energy is called potential energy. Gravitational potential energy describes the energy due to elevation. A car at a height of 50 m has more potential energy than a car at a height of 25 m. This may be understood more easily if the car is allowed to drop from its height. On impact with the earth at 0 m, the car that initially rested at 50 m will have more kinetic energy because it was moving faster (allowed more time to accelerate). The idea that potential energy can convert to kinetic energy is the first idea of energy transfer. Transfers between kinetic and potential energy represent one type of account balance rocket scientists need be aware of.

$$\text{Potential Energy} = (\text{mass}) \times (\text{acceleration due to gravity}) \times (\text{elevation with respect to reference line}) .$$

Internal Energy of Matter

The third and most important concept of energy is reflected by temperature. The internal energy of matter is measured by its temperature. Hot water has more internal energy than the same amount of cold water. Internal energy is a measure of kinetic energy of the molecules and atoms that make up the substance. Since each atom or molecule is acting on its own accord, this internal energy is different from the bulk kinetic energy associated with the movement of the entire solid. The internal energy of matter is exhibited by molecular motion. The molecules of a gas at high temperature zip around their container constantly colliding with walls and other molecules. The molecules of a high temperature solid also move around a lot; however, since they are stuck together with other molecules, the most they can do is vibrate in place.

In a nutshell, the above forms of energy are studied in classical thermodynamics. Those forms of energy are allowed to transfer among each other as well as in to or out of a system. Thermodynamics essentially provides some definitions for interpreting thermodynamic systems. It then goes on to define an important rule about fairly balancing energy and one rule about the quality of energy. (some energy is more valuable) Understanding the framework and the few rules that govern macroscopic thermodynamics proves to be an incredibly powerful set of tools for analyzing a myriad of not only engineering problems, but issues of practical concern. CONTRIBUTION BY CHANGES

Category:Engineering Thermodynamics¹

¹ <http://en.wikibooks.org/wiki/Category%3AEngineering%20Thermodynamics>

3 Thermodynamic Systems

3.1 Properties of Pure Substances

A cursory review of properties will introduce the variables of thermodynamics to the student. Properties of substances are things such as mass, temperature, volume, and pressure. Properties are used to define the current state of a substance. Several more properties exist to describe substances in thermodynamics, but a stronger understanding of theory is required for their definition and application.

Properties can be *intensive*, if they are point properties (properties that make sense for a point) or *extensive*, if they depend on the amount of matter in the system. Examples of extensive properties of systems are mass of system, number of moles of a substance in a system, and overall or total volume of a system. These properties depend on how much matter of the system you measure. Examples of intensive properties are pressure, temperature, density, volume per mass, molar volume (which is volume per mole), and average molecular weight (or molecular mass). These properties are the same regardless of how you vary the amount of mass of the substance.

Properties are like the variables for substances in that their values are all related by an equation. The relationship between properties is expressed in the form of an equation which is called an *equation of state*. Perhaps the most famous state equation is the Ideal Gas Law. The ideal gas law relates the pressure, volume, and temperature of an ideal gas to one another.

3.1.1 Volume

The SI unit for volume is m^3 . Volume is an extensive property, but both volume per mass and molar volume are intensive properties since they do not depend on the measured mass of the system. A process during which the volume of the system remains constant is called an *isochoric* (or *isometric*) process.

3.1.2 Pressure

The SI unit for pressure is Pa (Pascal), which is equivalent to a $N/(m^2)$. Pressure is an intensive property. A process in which pressure remains constant is called *isobaric* process.

3.1.3 Temperature

Temperature, the degree of hotness or coldness of a body. Defined based on the zeroth law of thermodynamics, is a fundamental concept of thermodynamics. We know that a body at high temperature will transfer energy to one at lower temperature. Consider two bodies with different temperatures in contact with each other. Net energy transfer will be from the hotter body to the colder body. At some point, the net energy transfer will be zero, and the bodies are said to be in *thermal equilibrium*. Bodies in thermal equilibrium are defined to have the same temperature.

3.2 Thermodynamic Systems

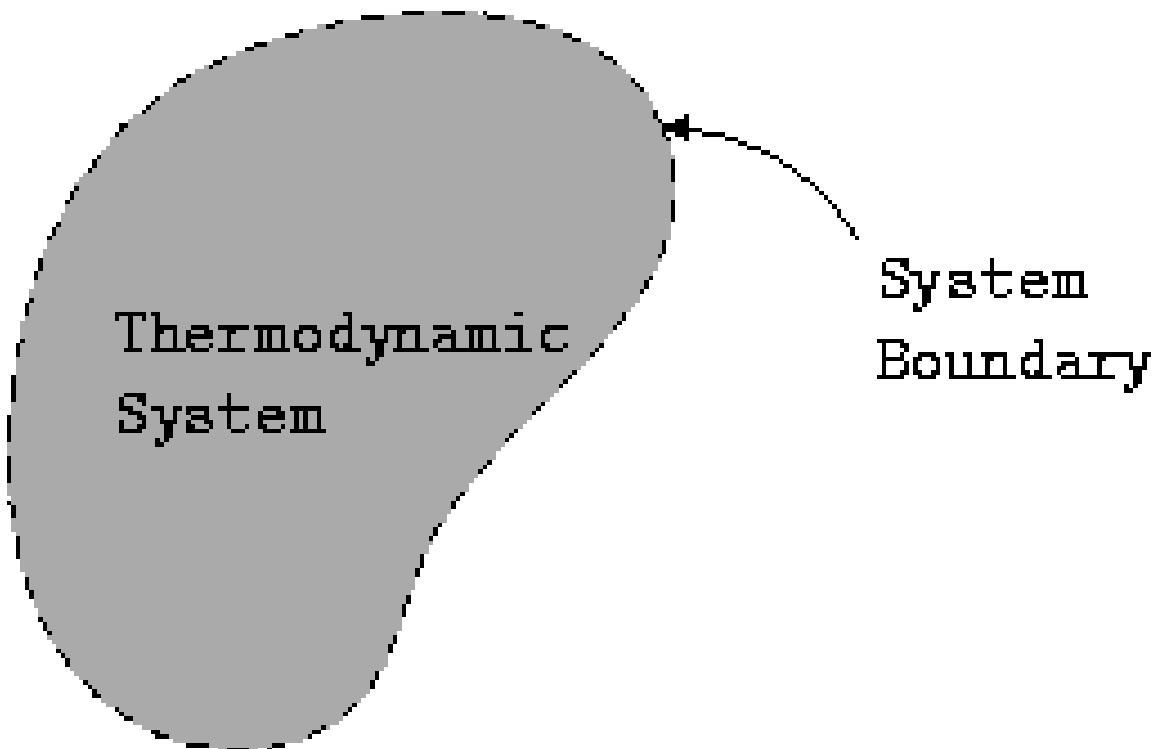


Figure 1 Thermodynamic System

In general, a system is a collection of objects, and there is a lot of subtlety in the way it is defined, as in set theory. However, in thermodynamics, it is a much more straightforward concept. A *thermodynamic system* is defined as a volume in space or a well defined set of materials (matter). The imaginary outer edge of the system is called its *boundary*.

As can be seen from the definition, the boundary can be fixed or moving. A system in which matter crosses the boundary is called an *open* system. In simple terms, a system which can exchange matter as well as energy with surroundings is an open system. Whereas a system which can exchange only energy with surrounding is a closed system. ex: liquid in sealed tube. The above image shows a piston cylinder arrangement, where a gas is compressed by the piston. The dotted lines represent the system boundary. As can be seen, due to an

opening in the cylinder, gas can escape outside as the piston moves inwards, and gas enters the system when the piston moves outwards. Thus, it is an open system.

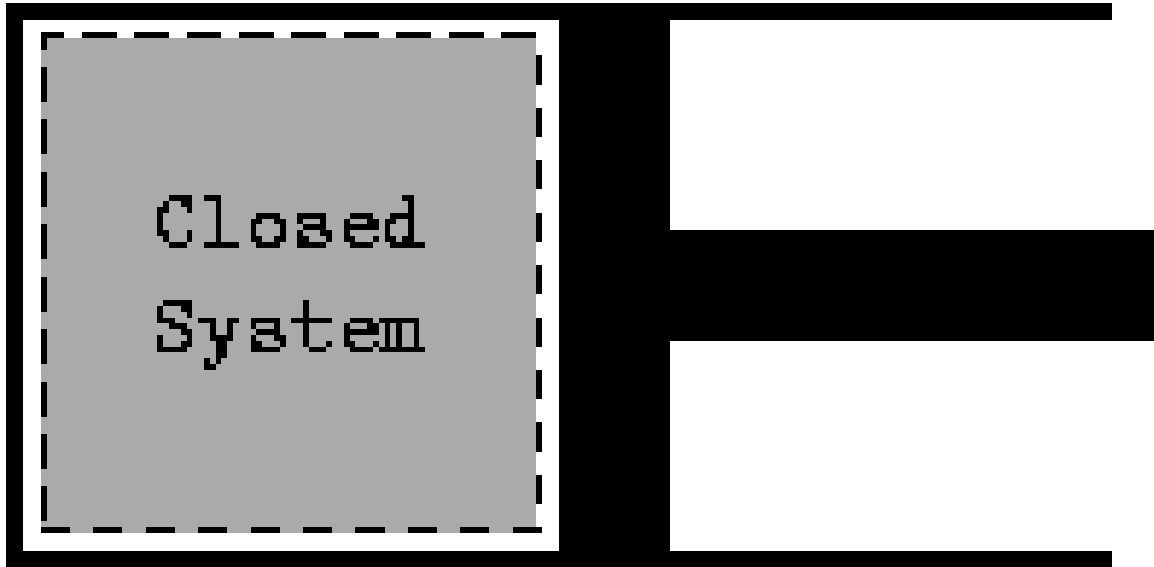


Figure 2 closed system

Now consider a similar system, but one in which gas cannot escape. In practice, there might be some space between the piston and the cylinder, but we can ignore it for modeling purposes. Thus the model of this configuration is a closed system.

The region outside the system is called the *surroundings*. The system and the surroundings together are called the *Universe*. A system which does not exchange matter or energy with the surroundings is called an *isolated system*.

Another term sometimes used instead of *system* is *control volume*. In the case of a closed system, in which the mass of matter inside the system remains constant, the control volume is referred to as *control mass*. A control volume is said to be enclosed by a *control surface*.

3.2.1 Systems

Classical thermodynamics deals with systems in *equilibrium*. The equilibrium state is defined by the values of observable quantities in the system. These are called *system properties*.

The minimum number of variables required to describe the system depends on the complexity or *degrees of freedom* of the system. Degrees of freedom refer to the number of properties that can be varied independently of each other in a system. Some of the common system variables are pressure, temperature, and density, though any other physical properties may be used.

Consistent with the axiomatic nature of subject development, many of the relationships between physical properties cannot be completely specified without further development of theory. What is good about classical thermodynamics is that many of the axioms stated

here can be derived using techniques of statistical thermodynamics. And statistical thermodynamics gives results in many cases where classical thermodynamics fails, such as in the specific heats of gases with many degrees of freedom. In some sense, the relationship between classical and statistical thermodynamics is similar to the one between classical and quantum mechanics, *i.e.* , classical thermodynamics approximates statistical thermodynamics in the macroscopic limit.

3.2.2 Processes

A change in the system state is called a *process* . When the initial and final states of a process are the same, the process is called a *cycle* . If a process can be run in reverse with no change in the system + surroundings, then the process is called a *reversible* process. If a process is not reversible it is called an *irreversible* process.

3.2.3 Isothermal Process

An *isothermal* process is one in which the temperature remains constant. Please note that a process being isothermal does not imply anything about the heat transferred or work done, *i.e.* heat transfer may take place during an isothermal process. An isothermal process implies that the product of the volume and the pressure is constant for an ideal gas. *i.e.* $PV = \text{Constant}$

3.3 Zeroth Law of Thermodynamics

If a system *A* is in thermal equilibrium with another system *B* and also with a third system *C* , then all of the systems are in thermal equilibrium with each other. This is called the *zeroth law of thermodynamics* . This is how a thermometer works. If a thermometer is placed in a substance for temperature measurement, the thermometer's glass comes into thermal equilibrium with the substance. The glass then comes into thermal equilibrium with the liquid (mercury, alcohol, etc. . . .) inside the thermometer. Because the substance is in thermal equilibrium with the glass and the glass is in thermal equilibrium with the inner liquid, the substance and liquid must be in thermal equilibrium by the zeroth law. And because they are thermally equivalent, they must have the same temperature.

3.4 Temperature Measurement

Temperature is measured by observing some property of the system which varies with temperature. Such a property is called *thermometric property* , *e.g.*:

- The volumes of most liquids increase with temperature.
 - The length of a metal rod increases as the temperature increases.
 - The pressure of a constant volume of gas increases with temperature

It is useful to establish a temperature scale so that a cardinal relationship can be established between various systems at different temperatures. This is done by *defining* the temperature t as a function of a thermometric property X , such that the temperature is a linear function of X , *i.e.*, equal changes in the property X give rise to equal changes in the temperature. Such a linear function is $t = a + bX$, for which one needs to assign arbitrary temperatures to two values of X to find the values of the constants a and b .

For example, in the case of the *Celsius* scale, the measurements are based on properties of water at the boiling point and melting point. Suppose the value of the thermometric property is X_b for the normal boiling point and X_m for the normal melting point. Then the temperature is given by $t = 100 (X - X_m) / (X_b - X_m)$, where X is the thermometric property at temperature t , and we have chosen $t_m = 0^\circ\text{C}$ and $t_b = 100^\circ\text{C}$. The *normal* melting and boiling points are the temperatures of melting and boiling at 1 *atmosphere* pressure.

The major temperature scales are the Celsius scale ($^\circ\text{C}$), the Fahrenheit ($^\circ\text{F}$) and the Kelvin (K) scale. Note the absence of the $^\circ$ sign for kelvin—it is not degrees Kelvin, but kelvins, not capitalized when spelled out, and with the normal English plural which was added to the degree when Kelvin was an adjective modifying that unit.

Different thermometers are used for different temperature ranges. As the reader might have guessed by now, this means that the different thermometers will only agree on the fixed points. However, a set of thermometers have been carefully selected and calibrated so that this is not a big issue in practice.

The standard in this case is the *International Temperature Scale*, which was introduced in 1927, and revised in 1948, 1968, and 1990. The latest scale is denoted by T_{90} for the Kelvin scale and is defined from 0.65 K upwards. For instance, between 0.65 K and 5.0 K T_{90} is defined in terms of the vapor-pressure temperature relations of ^3He and ^4He . The ranges for different materials overlap and any of the valid materials can be used as a standard in the overlapping region.

3.5 The Ideal Gas

Recall that a thermodynamic system may have a certain substance or material whose quantity can be expressed in mass or moles in an overall volume. These are extensive properties of the system. If the substance is evenly distributed throughout the volume in question, then a value of volume per amount of substance may be used as an intensive property. For an example, for an amount called a *mole*¹, volume per mole is typically called *molar volume*. Also, a volume per mass for a specific substance may be called specific volume. In such cases, an equation of state may relate the three intensive properties, temperature, pressure, and molar or specific volume.

A simple but very useful equation of state is for an ideal gas. The ideal gas is a useful notion in thermodynamics, as it is a simple system that depends on two independent properties. An ideal gas is one that has no intermolecular interactions except for completely elastic

¹ http://en.wikipedia.org/wiki/Mole_%28unit%29%20

collisions with other molecules. For a closed system containing an ideal gas, the state can be specified by giving the values of any two of pressure, temperature, and molar volume.

Consider a system, an ideal gas enclosed in a container. Starting from an initial state 1, where the temperature is T_1 , its temperature is changed to T_2 through a constant pressure process and then a constant molar volume process, then the ratio of pressures is found to be the same as the ratio of molar volumes. Suppose the initial value of the pressure and molar volume are p_1 and V_1 respectively, and final value of pressure and molar volume are p_2 and V_2 respectively. Note that we haven't chosen a specific scale for the temperature (like say, the Celsius scale). Now, suppose we were to choose a scale such that $T_1 / T_2 = p_1 / p_2$, we can show that the value of pV/T is constant for an ideal gas, so that it obeys the gas equation $pV = RT$, where p is the absolute pressure, V is the molar volume, and R is a constant known as the universal gas constant². The temperature T is the absolute temperature in the ideal gas scale, and the scale is found to be the same as the thermodynamic temperature scale. The thermodynamic temperature scale will be defined after the statement of the second law of thermodynamics.

This equation $pV = RT$ is called the equation of state for an ideal gas, and is known as the ideal gas equation. Most common gases obey the ideal gas equation unless they are compressed or cooled to extreme states, so this is a very useful relation. A similar equation may be written where, for the specific type of gas, specific volume is used instead of molar volume and a specific gas constant is used instead of the universal gas constant. This then writes as $pv = mrT$.

² <http://en.wikipedia.org/wiki/gas%20constant%20>

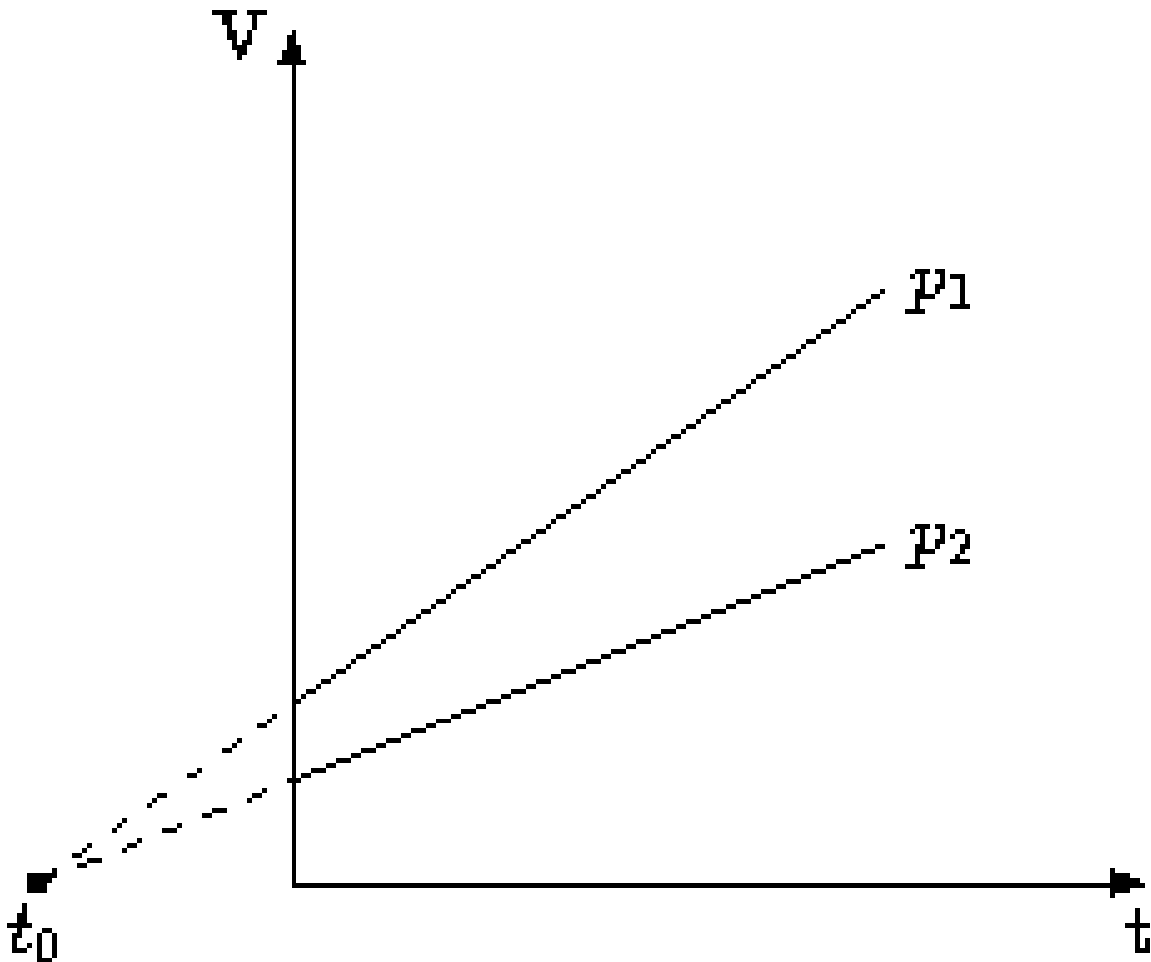


Figure 3 Ideal Gas Temperature

In the above image, the volume of an ideal gas at two different pressures p_1 and p_2 is plotted against the temperature in Celsius. If we extrapolate the two straight line graphs, they intersect the temperature axis at a point t_0 , where $t_0 = -273.15^\circ\text{C}$.

From experiment, it is easy to show that the thermodynamic temperature T is related to the Celsius temperature t by the equation: $T = t + 273.15$. The zero of thermodynamic temperature scale is 0 K, and its significance will be clear when we discuss the second law of thermodynamics.

Category:Engineering Thermodynamics³

³ <http://en.wikibooks.org/wiki/Category%3AEngineering%20Thermodynamics>

4 Zeroth Law

The Zeroth law of Thermodynamics can be stated as:

If two thermodynamic systems A and B are in thermal equilibrium, and B is also in thermal equilibrium with another system C, then A and C are in thermal equilibrium. OR

''' If a body isolated from the other environment is in thermal equilibrium with one body & is separately in thermal equilibrium with the another body then three bodies are said to be in the thermal equilibrium with each other.'''

This may seem obvious as we are quite familiar with this experiment. When we place in a cup of water (System A) a thermometer (System B) we wait a period of time until they reach equilibrium then read the measurement on the thermometer.

It is called the Zeroth Law as it is not derivable from the other laws and is often useful to understand the concept before presenting the other laws of thermodynamics.

It also states that at absolute zero temperature(i.e. zero Kelvin) all molecular motion inside a crystal ceases.

The application of zeroth law is mainly seen in the thermodynamic properties.

Source : http://en.wikipedia.org/wiki/Zeroth_law_of_thermodynamics¹<http://>

Category:Engineering Thermodynamics²

¹ <http://en.wikibooks.org/wiki/>

² <http://en.wikibooks.org/wiki/Category%3AEngineering%20Thermodynamics>

5 First Law

5.1 Energy

We use the notion of energy of a body from Newton's second law, and thus total energy is conserved. **Common forms of energy** in physics are potential and kinetic energy. The potential energy is usually the energy due to matter having certain position (configuration) in a field, commonly the gravitational field of Earth. Kinetic energy is the energy due to motion relative to a frame of reference. In thermodynamics, we deal with mainly work and heat, which are different manifestations of the energy in the universe.

5.2 Work

Work is said to be done by a system if the effect on the surroundings can be reduced solely to that of lifting a weight. Work is only ever done at the boundary of a system. Again, we use the intuitive definition of work, and this will be complete only with the statement of the second law of thermodynamics.

Consider a piston-cylinder arrangement as found in automobile engines. When the gas in the cylinder expands, pushing the piston outwards, it does work on the surroundings. In this case work done is mechanical. But how about other forms of energy like heat? The answer is that heat cannot be completely converted into work, with no other change, due to the second law of thermodynamics.

In the case of the piston-cylinder system, the work done during a cycle is given by W , where $W = -\int F dx = -\int p dV$, where $F = p A$, and p is the pressure on the inside of the piston (note the minus sign in this relationship). In other words, the work done is the area under the p - V diagram. Here, F is the external opposing force, which is equal and opposite to that exerted by the system. A corollary of the above statement is that a system undergoing free expansion does no work. The above definition of work will only hold for the quasi-static case, when the work done is reversible work.

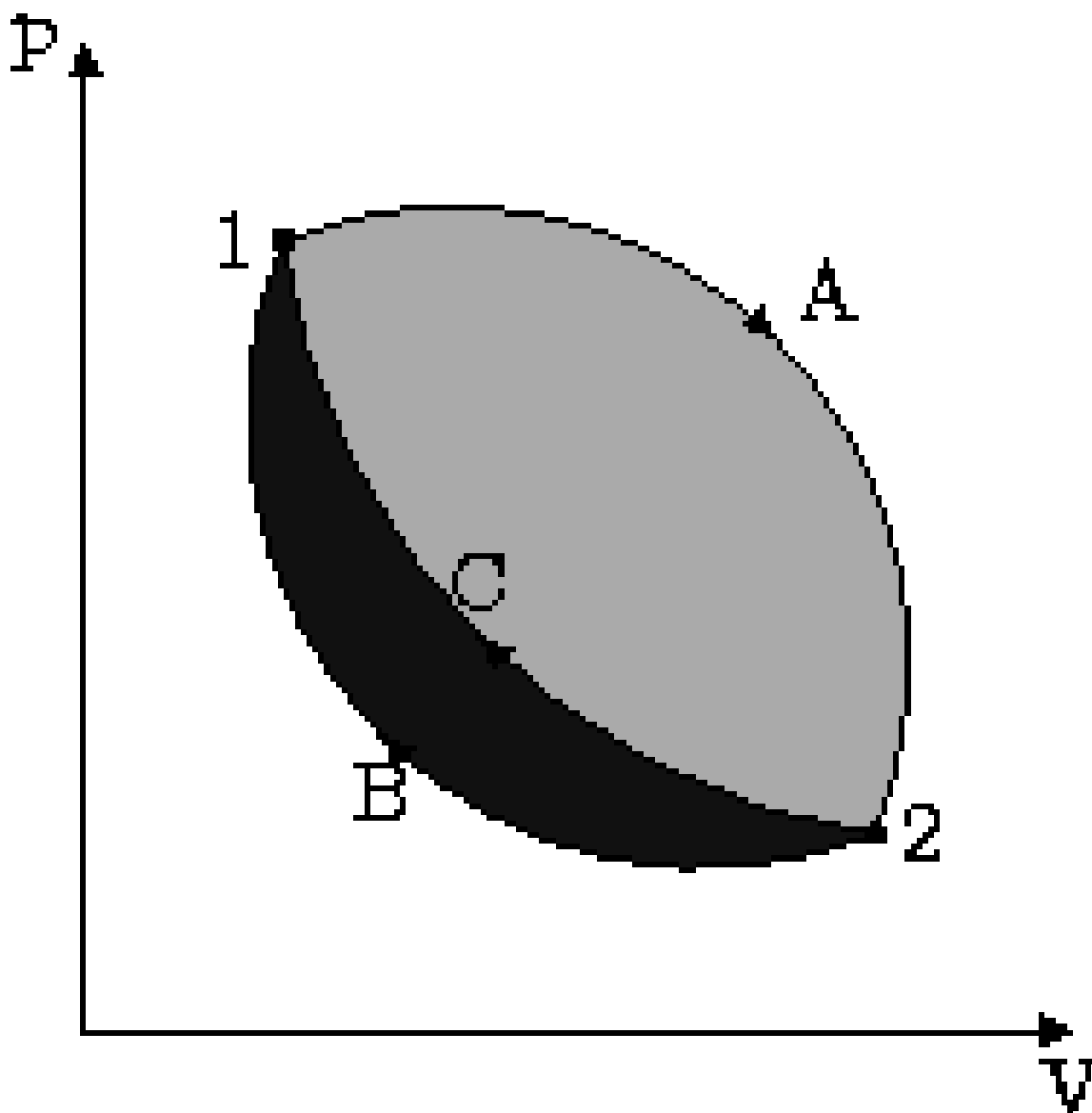


Figure 4 Work not a State Function

A consequence of the above statement is that work done is not a state function, since it depends on the path (which curve you consider for integration from state 1 to 2). For a system in a cycle which has states 1 and 2, the work done depends on the path taken during the cycle. If, in the cycle, the movement from 1 to 2 is along *A* and the return is along *C*, then the work done is the lightly shaded area. However, if the system returns to 1 via the path *B*, then the work done is larger, and is equal to the sum of the two areas.

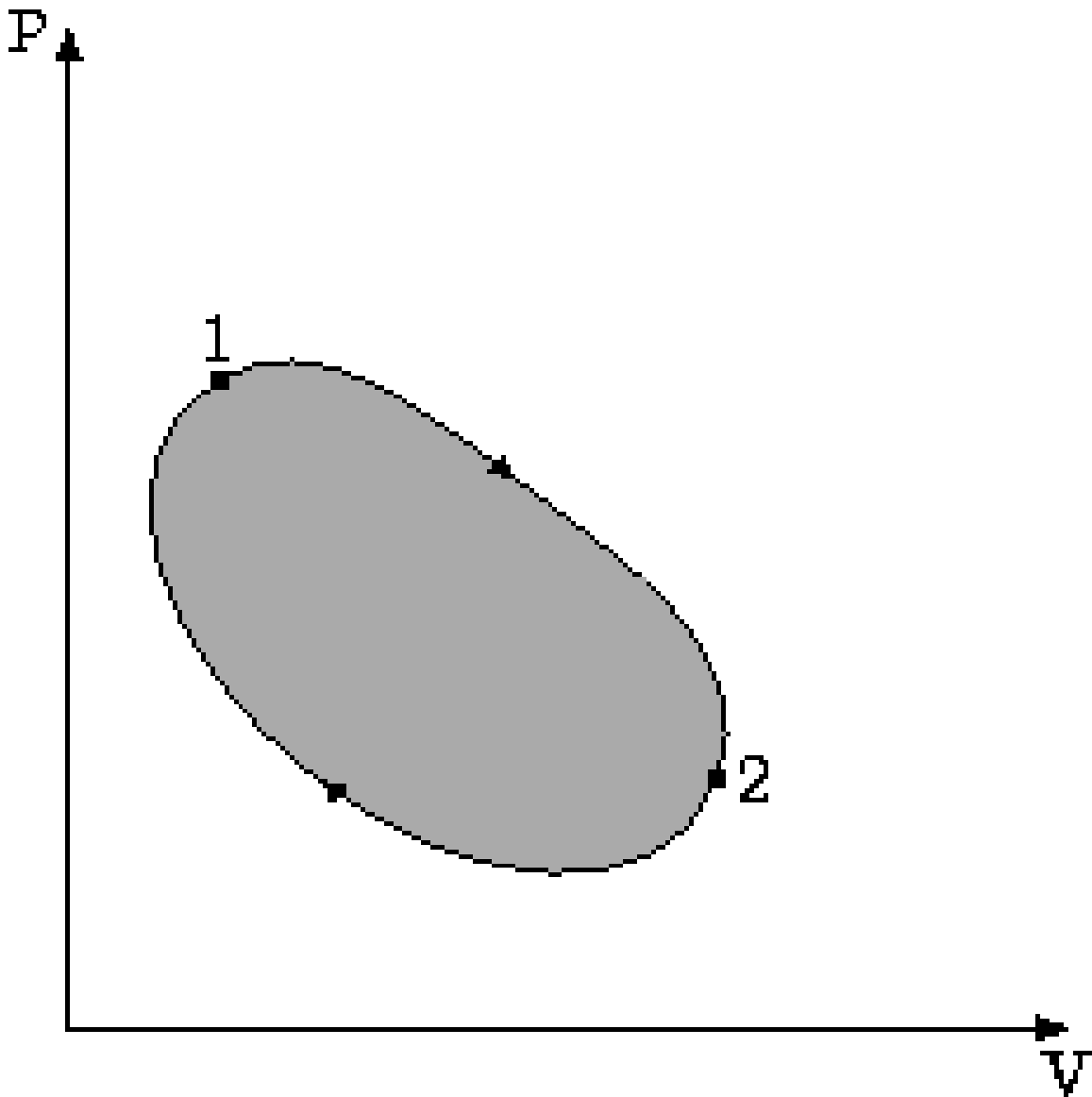


Figure 5 Indicator Diagram p vs V

The above image shows a typical indicator diagram as output by an automobile engine. The shaded region is proportional to the work done by the engine, and the volume V in the x -axis is obtained from the piston displacement, while the y -axis is from the pressure inside the cylinder. The work done in a cycle is given by W , where

$$W = - \oint p dV$$

Work done by the system is negative, and work done on the system is positive, by the convention used in this book.

5.2.1 Flow Energy

So far we have looked at the work done to compress fluid in a system. Suppose we have to introduce some amount of fluid into the system at a pressure p . Remember from the definition of the system that matter can enter or leave an open system. Consider a small amount of fluid of mass dm with volume dV entering the system. Suppose the area of cross section at the entrance is A . Then the distance the force pA has to push is $dx = dV/A$. Thus, the work done to introduce a small amount of fluid is given by pdV , and the work done per unit mass is pv , where $v = dV/dm$ is the specific volume. This value of pv is called the flow energy.

5.2.2 Examples of Work

The amount of work done in a process depends on the irreversibilities present. A complete discussion of the irreversibilities is only possible after the discussion of the second law. The equations given above will give the values of work for quasi-static processes, and many real world processes can be approximated by this process. However, note that work is only done if there is an opposing force in the boundary, and that a volume change is not strictly required.

5.2.3 Work in a Polytropic Process

Consider a polytropic process $pV^n = C$, where C is a constant. If the system changes its states from 1 to 2, the work done is given by

$$W = - \int_{V_1}^{V_2} \frac{C}{V^n} dV = \frac{p_2 V_2 - p_1 V_1}{1-n}$$

And additionally, if $n=1$

$$W = - \int_{V_1}^{V_2} \frac{C}{V} dV = -C \ln \frac{V_2}{V_1}$$

5.3 Heat

Before thermodynamics was an established science, the popular theory was that heat was a fluid, called *caloric*, that was stored in a body. Thus, it was thought that a hot body transferred heat to a cold body by transferring some of this fluid to it. However, this was soon disproved by showing that heat was generated when drilling bores of guns, where both the drill and the barrel were initially cold.

Heat is the energy exchanged due to a temperature difference. As with work, heat is defined at the boundary of a system and is a path function. Heat rejected by the system is negative, while the heat absorbed by the system is positive.

5.3.1 Specific Heat

The *specific heat* of a substance is the amount of heat required for a unit rise in the temperature in a unit mass of the material. If this quantity is to be of any use, the amount of heat transferred should be a linear function of temperature. This is certainly true for ideal gases. This is also true for many metals and also for real gases under certain conditions. In general, we can only talk about the average specific heat, $c_{av} = Q/m\Delta T$. Since it was customary to give the specific heat as a property in describing a material, methods of analysis came to rely on it for routine calculations. However, since it is only constant for some materials, older calculations became very convoluted for newer materials. For instance, for finding the amount of heat transferred, it would have been simple to give a chart of $Q(\Delta T)$ for that material. However, following convention, the tables of $c_{av}(\Delta T)$ were given, so that a double iterative solution over c_{av} and T was required.

Calculating specific heat requires us to specify what we do with Volume and Pressure when we change temperature. When Volume is fixed, it is called specific heat at constant volume (C_v). When Pressure is fixed, it is called specific heat at constant pressure (C_p).

5.3.2 Latent Heat

It can be seen that the specific heat as defined above will be infinitely large for a phase change, where heat is transferred without any change in temperature. Thus, it is much more useful to define a quantity called *latent heat*, which is the amount of energy required to change the phase of a unit mass of a substance at the phase change temperature.

5.3.3 Adiabatic Process

An *adiabatic* process is defined as one in which there is no heat transfer with the surroundings, that is, the change in amount of energy $dQ=0$. A gas contained in an insulated vessel undergoes an adiabatic process. Adiabatic processes also take place even if the vessel is not insulated if the process is fast enough that there is not enough time for heat to escape (*e.g.* the transmission of sound through air). Adiabatic processes are also ideal approximations for many real processes, like expansion of a vapor in a turbine, where the heat loss is much smaller than the work done.

5.4 First Law of Thermodynamics

5.4.1 Joule Experiments

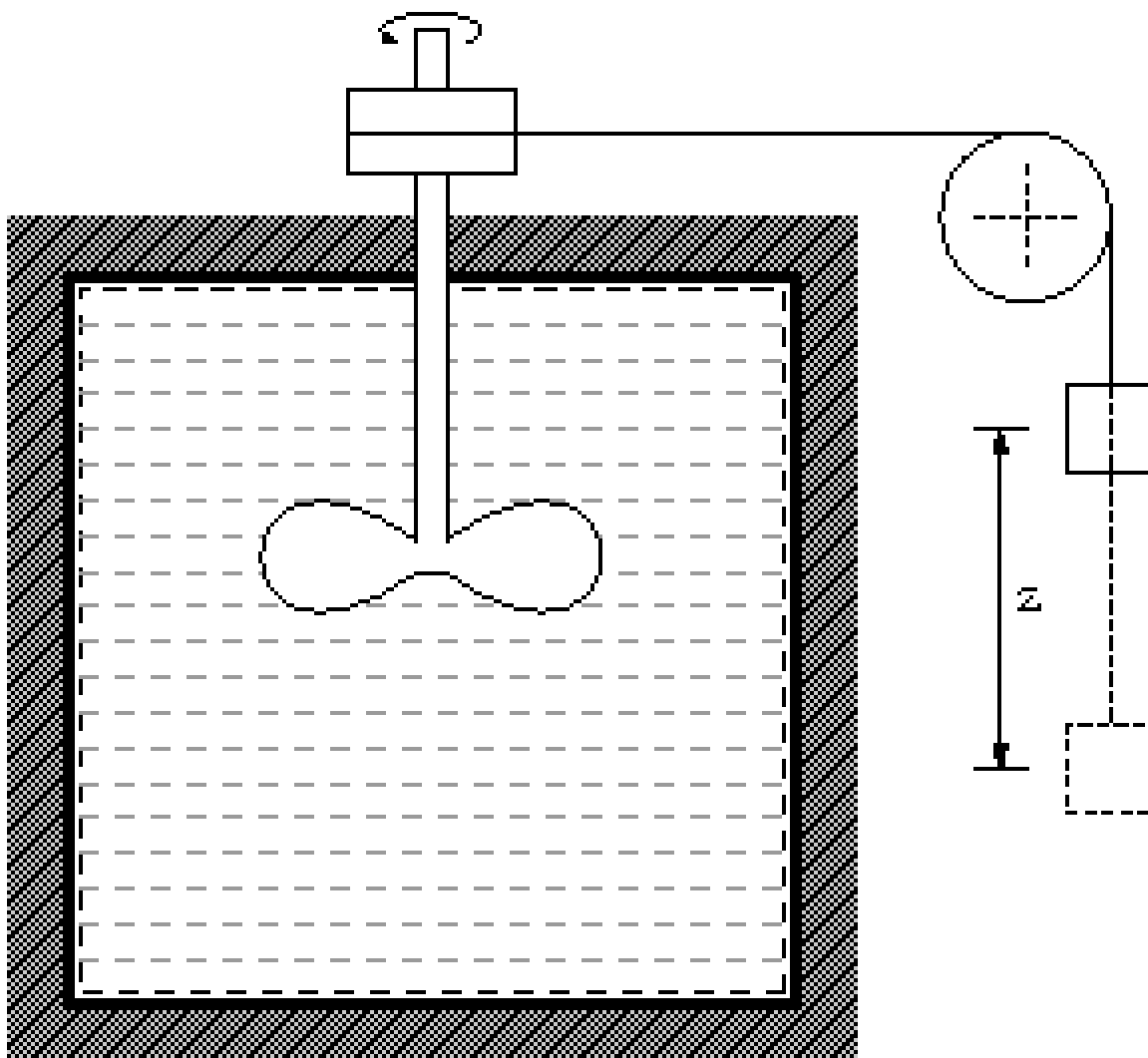


Figure 6 Joule's Experiments for First Law

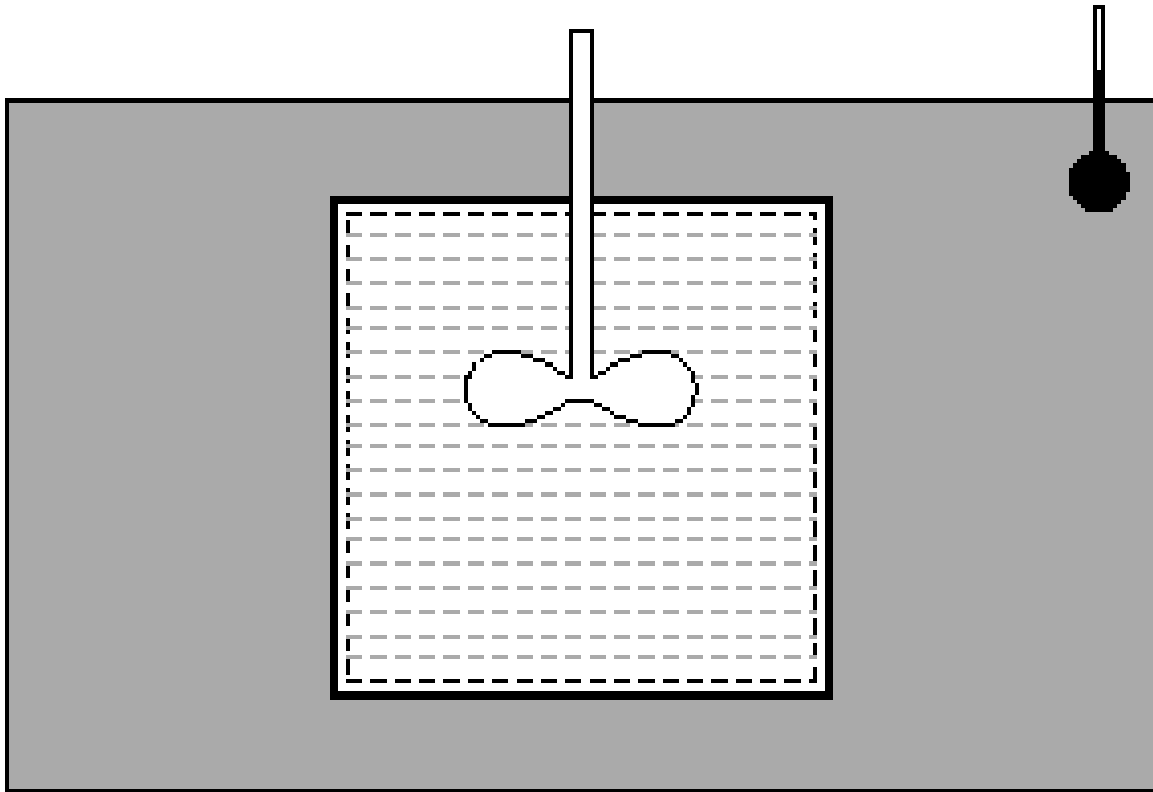


Figure 7 Joule's Experiments for First Law

It was well known that heat and work both change the energy of a system. Joule conducted a series of experiments which showed the relationship between heat and work in a thermodynamic cycle for a system. He used a paddle to stir an insulated vessel filled with fluid. The amount of work done on the paddle was noted (the work was done by lowering a weight, so that work done = mgz). Later, this vessel was placed in a bath and cooled. The energy involved in increasing the temperature of the bath was shown to be equal to that supplied by the lowered weight. Joule also performed experiments where electrical work was converted to heat using a coil and obtained the same result.

5.5 Statement of the First Law for a Closed System

The first law states that *when heat and work interactions take place between a closed system and the environment, the algebraic sum of the heat and work interactions for a cycle is zero*.

Mathematically, this is equivalent to

$$dQ + dW = 0 \text{ for any cycle closed to mass flow}$$

Q is the heat transferred, and W is the work done on or by the system. Since these are the only ways energy can be transferred, this implies that the total energy of the system in the cycle is a constant.

One consequence of the statement is that the total energy of the system is a property of the system. This leads us to the concept of internal energy.

5.5.1 Internal Energy

In thermodynamics, the *internal energy* is the energy of a system due to its temperature. The statement of first law refers to thermodynamic cycles. Using the concept of internal energy it is possible to state the first law for a non-cyclic process. Since the first law is another way of stating the conservation of energy, the energy of the system is the sum of the heat and work input, *i.e.* , $\Delta E = Q + W$. Here E represents the internal energy (U) of the system along with the kinetic energy (KE) and the potential energy (PE) ($E = U + K.E. + P.E.$) and is called the *total energy* of the system. This is the statement of the first law for non-cyclic processes, as long as they are still closed to the flow of mass. The KE and PE terms are relative to an external reference point *i.e.* the system is the gas within a ball, the ball travels in a trajectory that varies in height H and velocity V and subsequently KE and PE with time, but this has no affect upon the energy of the gas molecules within the ball, which is dictated only by the internal energy of the system (U). Thermodynamics does not define the nature of the internal energy, but it can be rationalised using other theories (*i.e.* the gas kinetic theory), but in this case is due to the KE and PE of the gas molecules within the ball, not to be mistaken with the KE and PE of the ball itself.

For gases, the value of $K.E.$ and $P.E.$ is quite small, so the important term is the internal energy function U . In particular, since for an ideal gas the state can be specified using two variables, the state variable u is given by $u(v, T)$, where v is the specific volume and T is the temperature.

Introducing this temperature dependence explicitly is important in many calculations. For this purpose, the constant-volume heat capacity is defined as follows: $c_v = (\partial u / \partial t)_v$, where c_v is the specific heat at constant volume. A constant-pressure heat capacity will be defined later, and it is important to keep them straight. The important point here is that the other variable that U depends on "naturally" is v , so to isolate the temperature dependence of U you want to take the derivative at constant v .

5.5.2 Internal Energy for an Ideal Gas

In the previous section, the internal energy of an ideal gas was shown to be a function of both the volume and temperature. Joule performed an experiment where a gas at high pressure inside a bath at the same temperature was allowed to expand into a larger volume.

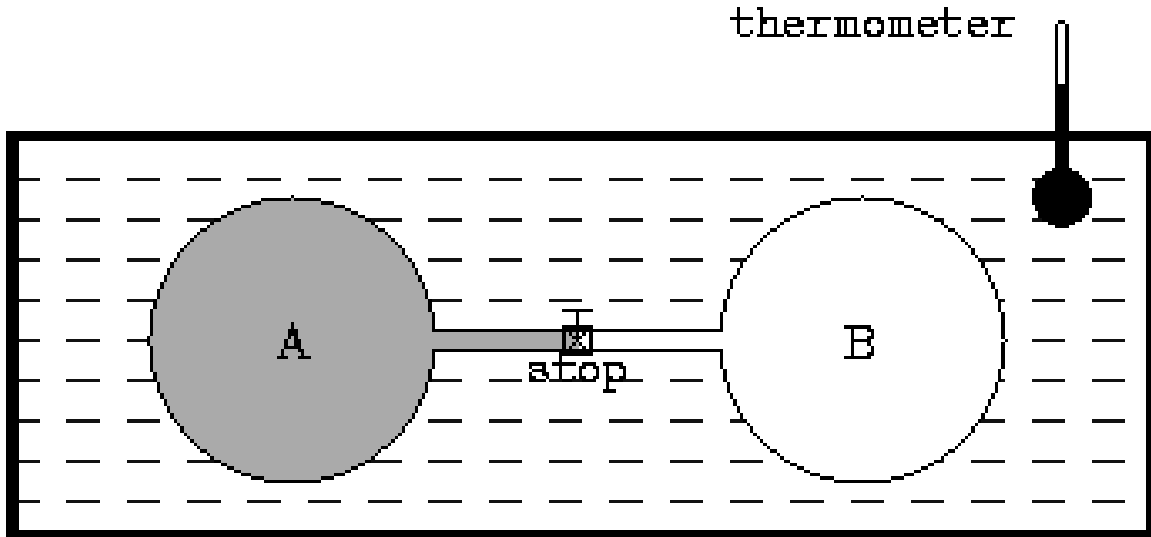


Figure 8 Joule's Experiment Temperature Invariance

In the above image, two vessels, labeled A and B, are immersed in an insulated tank containing water. A thermometer is used to measure the temperature of the water in the tank. The two vessels A and B are connected by a tube, the flow through which is controlled by a stop. Initially, A contains gas at high pressure, while B is nearly empty. The stop is removed so that the vessels are connected and the final temperature of the bath is noted.

The temperature of the bath was unchanged at the end of the process, showing that the internal energy of an ideal gas was the function of temperature alone. Thus *Joule's law* is stated as $(\partial u / \partial v)_t = 0$.

5.6 Enthalpy

According to the first law, $dQ + dW = dE$

If all the work is pressure volume work, then we have

$$dW = - p dV$$

$$\Rightarrow dQ = dU + p dV = d(U + pV) - V dp$$

$$\Rightarrow d(U + pV) = dQ + V dp$$

We define $H \equiv U + pV$ as the *enthalpy* of the system, and $h = u + pv$ is the specific enthalpy. In particular, for a constant pressure process,

$$\Delta Q = \Delta H$$

With arguments similar to that for c_v , $c_p = (\partial h / \partial t)_p$. Since h , p , and t are state variables, c_p is a state variable. As a corollary, for ideal gases, $c_p = c_v + R$, and for incompressible fluids, $c_p = c_v$

5.6.1 Throttling

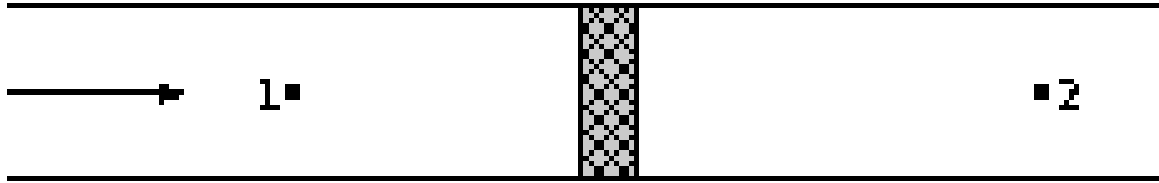


Figure 9 Throttling Process

Throttling is the process in which a fluid passing through a restriction loses pressure. It usually occurs when fluid passes through small orifices like porous plugs. The original throttling experiments were conducted by Joule and Thompson. As seen in the previous section, in adiabatic throttling the enthalpy is constant. What is significant is that for ideal gases, the enthalpy depends only on temperature, so that there is no temperature change, as there is no work done or heat supplied. However, for real gases, below a certain temperature, called the *inversion point*, the temperature drops with a drop in pressure, so that throttling causes cooling, *i.e.*, $p_1 < p_2 \Rightarrow T_1 < T_2$. The amount of cooling produced is quantified by the Joule-Thomson coefficient $\mu_{JT} = (\partial T / \partial p)_h$. For instance, the inversion temperature for air is about 400°C .

6 Second Law

6.1 Introduction

{EngTherm}}

6.2 Introduction

The first law is a statement of energy conservation. The rise in temperature of a substance when work is done is well known. Thus work can be completely converted to heat. However, we observe that in nature, we don't see the conversion in the other direction spontaneously.

The statement of the second law is facilitated by using the concept of *heat engines*. Heat engines work in a cycle and convert heat into work. A *thermal reservoir* is defined as a system which is in equilibrium and large enough so that heat transferred to and from it does not change its temperature appreciably.

Figure 10 Heat Engine

Heat engines work between two thermal reservoirs, the low temperature reservoir and the high temperature reservoir. The performance of a heat engine is measured by its *thermal efficiency*, which is defined as the ratio of work output to heat input, *i.e.*, $\eta = W/Q_1$, where W is the net work done, and Q_1 is heat transferred from the high temperature reservoir.

Figure 11 Heat Pumps

Heat pumps transfer heat from a low temperature reservoir to a high temperature reservoir using external work, and can be considered as reversed heat engines.

6.3 Statement of the Second Law of Thermodynamics

6.3.1 Kelvin-Planck Statement

It is impossible to construct a heat engine which will operate continuously and convert all the heat it draws from a reservoir into work.

OR

IT IS IMPOSSIBLE TO HAVE A HEAT ENGINE WHICH WORKS IN CYCLE AND DOES WORK BY EXCHANGING HEAT WITH ONLY ONE RESERVOIR.

6.3.2 Clausius Statement

It is impossible to construct a heat pump which will transfer heat from a low temperature reservoir to a high temperature reservoir without using external work.

"OR"

it is impossible to flow heat from low temperature (sink) to high temperature (source) without using expenditures.

6.3.3 PMM2

A *perpetual motion machine of the second kind*, or *PMM2* is one which converts all the heat input into work while working in a cycle. A PMM2 has an η_{th} of 1.

6.3.4 Equivalence of Clausius and Kelvin-Planck Statements

Figure 12 Kelvin-Planck from Clausius

Suppose we can construct a heat pump which transfers heat from a low temperature reservoir to a high temperature one without using external work. Then, we can couple it with a heat engine in such a way that the heat removed by the heat pump from the low temperature reservoir is the same as the heat rejected by the heat engine, so that the combined system is now a heat engine which converts heat to work without any external effect. This is thus in violation of the Kelvin-Planck statement of the second law.

Figure 13 Clausius from Kelvin-Planck

Now suppose we have a heat engine which can convert heat into work without rejecting heat anywhere else. We can combine it with a heat pump so that the work produced by the engine is used by the pump. Now the combined system is a heat pump which uses no external work, violating the Clausius statement of the second law.

Thus, we see that the Clausius and Kelvin-Planck statements are equivalent, and one necessarily implies the other.

6.4 Carnot Cycle

Nicholas Sadi Carnot devised a reversible cycle in 1824 called the *Carnot cycle* for an engine working between two reservoirs at different temperatures. It consists of two reversible isothermal and two reversible adiabatic processes. For a cycle 1-2-3-4, the working material

1. Undergoes isothermal expansion in 1-2 while absorbing heat from high temperature reservoir
2. Undergoes adiabatic expansion in 2-3
3. Undergoes isothermal compression in 3-4, and
4. Undergoes adiabatic compression in 4-1.

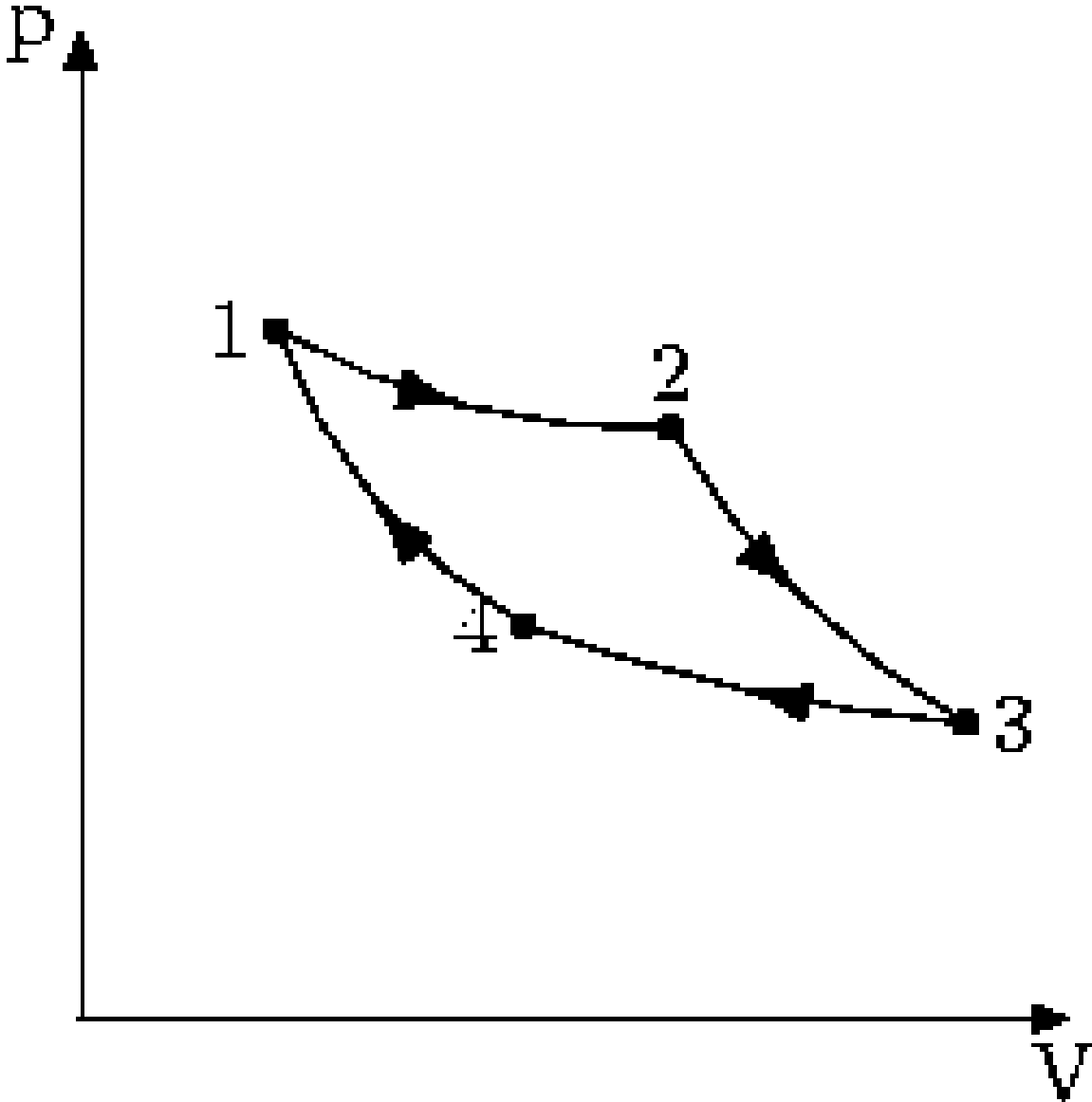


Figure 14 Carnot Cycle P-V Diagram

Heat is transferred to the working material during 1-2 (Q_1) and heat is rejected during 3-4 (Q_2). The thermal efficiency is thus $\eta_{th} = W/Q_1$. Applying first law, we have, $W = Q_1 - Q_2$, so that $\eta_{th} = 1 - Q_2/Q_1$.

Carnot's principle states that

1. No heat engine working between two thermal reservoirs is more efficient than the Carnot engine, and
2. All Carnot engines working between reservoirs of the same temperature have the same efficiency.

The proof by contradiction of the above statements come from the second law, by considering cases where they are violated. For instance, if you had a Carnot engine which was more efficient than another one, we could use that as a heat pump (since processes in a Carnot cycle are reversible) and combine with the other engine to produce work without heat rejection, to violate the second law. A corollary of the Carnot principle is that Q_2/Q_1 is purely a function of t_2 and t_1 , the reservoir temperatures. Or,

$$\frac{Q_2}{Q_1} = \phi(t_1, t_2)$$

6.5 Thermodynamic Temperature Scale

Lord Kelvin used Carnot's principle to establish the thermodynamic temperature scale which is independent of the working material. He considered three temperatures, t_1 , t_2 , and t_3 , such that $t_1 > t_3 > t_2$.

As shown in the previous section, the ratio of heat transferred only depends on the temperatures. The first law is a statement of energy conservation. The rise in temperature of a substance when work is done is well known. Thus work can be completely converted to heat. However, we observe that in nature, we don't see the conversion in the other direction spontaneously.

The statement of the second law is facilitated by using the concept of *heat engines*. Heat engines work in a cycle and convert heat into work. A *thermal reservoir* is defined as a system which is in equilibrium and large enough so that heat transferred to and from it does not change its temperature appreciably.

Figure 15 Heat Engine

Heat engines usually work between two thermal reservoirs, the low temperature reservoir and the high temperature reservoir. The performance of a heat engine is measured by its *thermal efficiency*, which is defined as the ratio of work output to heat input, *i.e.*, $\eta = W/Q_1$, where W is the net work done, and Q_1 is heat transferred from the high temperature reservoir.

Figure 16 Heat Pumps

Heat pumps transfer heat from a low temperature reservoir to a high temperature reservoir using external work, and can be considered as reversed heat engines.

6.6 Statement of the Second Law of Thermodynamics

6.6.1 Kelvin-Planck Statement

It is impossible to construct a heat engine which will operate continuously and convert all the heat it draws from a reservoir into work.

6.6.2 Clausius Statement

It is impossible to construct a heat pump which will transfer heat from a low temperature reservoir to a high temperature reservoir without using external work.

"OR"

it is impossible to flow heat from low temperature(sink) to high temperature(source) without using expenditures.

=== PMM2 ===

A *perpetual motion machine of the second kind*, or *PMM2* is one which converts all the heat input into work while working in a cycle. A PMM2 has an η_{th} of 1.

6.6.3 Equivalence of Clausius and Kelvin-Planck Statements

Figure 17 Kelvin-Planck from Clausius

Suppose we can construct a heat pump which transfers heat from a low temperature reservoir to a high temperature one without using external work. Then, we can couple it with a heat engine in such a way that the heat removed by the heat pump from the low temperature reservoir is the same as the heat rejected by the heat engine, so that the combined system is now a heat engine which converts heat to work without any external effect. This is thus in violation of the Kelvin-Planck statement of the second law.

Figure 18 Clausius from Kelvin-Planck

Now suppose we have a heat engine which can convert heat into work without rejecting heat anywhere else. We can combine it with a heat pump so that the work produced by the engine is used by the pump. Now the combined system is a heat pump which uses no external work, violating the Clausius statement of the second law.

Thus, we see that the Clausius and Kelvin-Planck statements are equivalent, and one necessarily implies the other.

6.7 Carnot Cycle

Nicholas Sadi Carnot devised a reversible cycle in 1824 called the *Carnot cycle* for an engine working between two reservoirs at different temperatures. It consists of two reversible isothermal and two reversible adiabatic processes. For a cycle 1-2-3-4, the working material

1. Undergoes isothermal expansion in 1-2 while absorbing heat from high temperature reservoir
2. Undergoes adiabatic expansion in 2-3
3. Undergoes isothermal compression in 3-4, and
4. Undergoes adiabatic compression in 4-1.

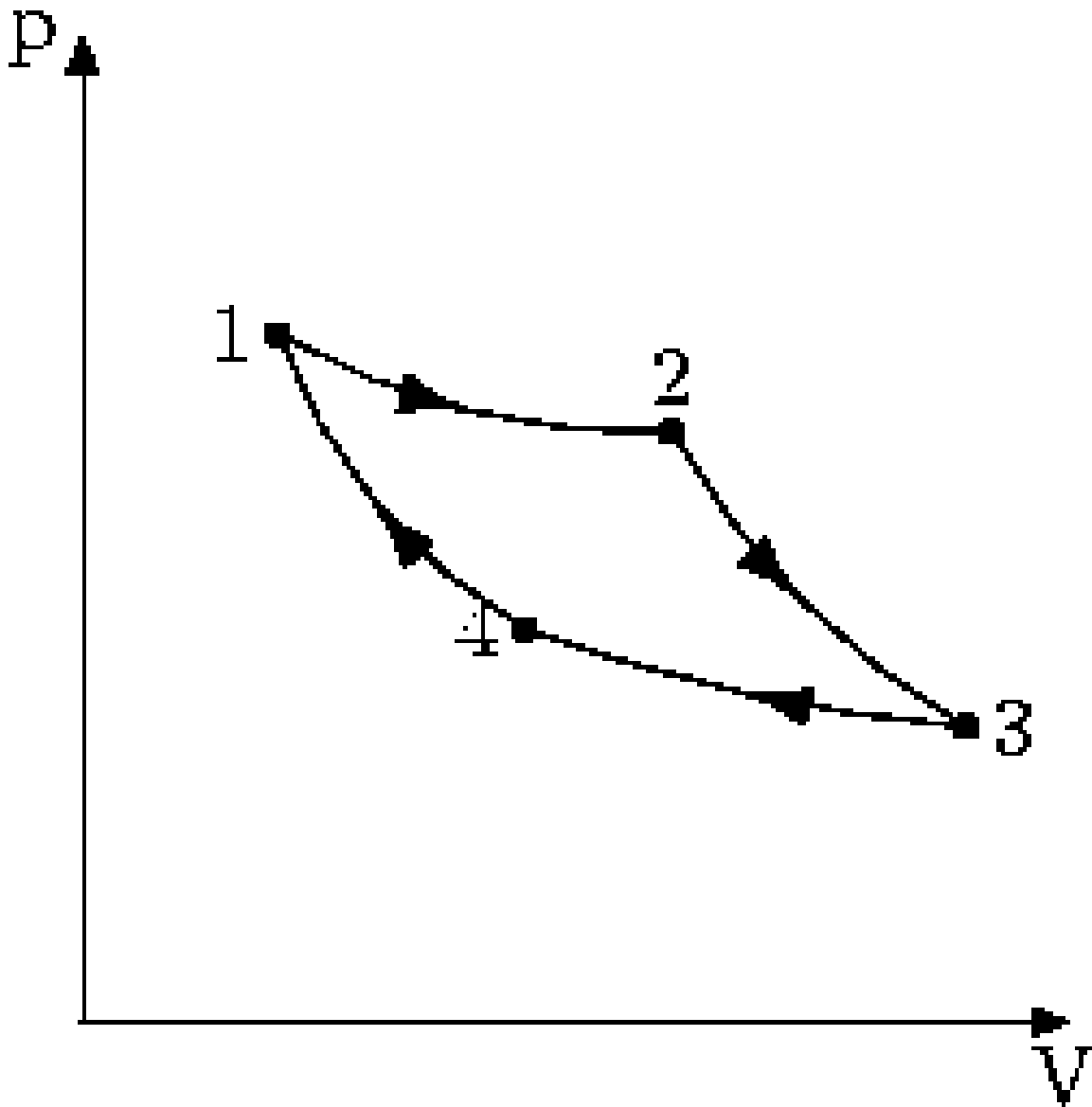


Figure 19 Carnot Cycle P-V Diagram

Heat is transferred to the working material during 1-2 (Q_1) and heat is rejected during 3-4 (Q_2). The thermal efficiency is thus $\eta_{th} = W/Q_1$. Applying first law, we have, $W = Q_1 - Q_2$, so that $\eta_{th} = 1 - Q_2/Q_1$.

Carnot's principle states that

1. No heat engine working between two thermal reservoirs is more efficient than the Carnot engine, and
2. All Carnot engines working between reservoirs of the same temperature have the same efficiency.

The proof by contradiction of the above statements come from the second law, by considering cases where they are violated. For instance, if you had a Carnot engine which was more efficient than another one, we could use that as a heat pump (since processes in a Carnot

cycle are reversible) and combine with the other engine to produce work without heat rejection, to violate the second law. A corollary of the Carnot principle is that Q_2/Q_1 is purely a function of t_2 and t_1 , the reservoir temperatures. Or,

$$\frac{Q_1}{Q_2} = \phi(t_1, t_2)$$

6.8 Thermodynamic Temperature Scale

Lord Kelvin used Carnot's principle to establish the thermodynamic temperature scale which is independent of the working material. He considered three temperatures, t_1 , t_2 , and t_3 , such that $t_1 > t_3 > t_2$.

As shown in the previous section, the ratio of heat transferred only depends on the temperatures. Considering reservoirs 1 and 2:

$$\frac{Q_1}{Q_2} = \phi(t_1, t_2)$$

Considering reservoirs 2 and 3:

$$\frac{Q_2}{Q_3} = \phi(t_2, t_3)$$

Considering reservoirs 1 and 3:

$$\frac{Q_1}{Q_3} = \phi(t_1, t_3)$$

Eliminating the heat transferred, we have the following condition for the function ϕ .

$$\phi(t_1, t_2) = \frac{\phi(t_1, t_3)}{\phi(t_2, t_3)}$$

Now, it is possible to choose an arbitrary temperature for 3, so it is easy to show using elementary multivariate calculus that ϕ can be represented in terms of an increasing function of temperature ζ as follows:

$$\phi(t_1, t_2) = \frac{\zeta(t_1)}{\zeta(t_2)}$$

Now, we can have a one to one association of the function ζ with a new temperature scale called the *thermodynamic temperature scale*, T , so that

$$\frac{Q_1}{Q_2} = \frac{T_1}{T_2}$$

Thus we have the thermal efficiency of a Carnot engine as

$$\eta_{th} = 1 - \frac{T_2}{T_1}$$

The thermodynamic temperature scale is also known as the Kelvin scale, and it needs only one fixed point, as the other one is absolute zero. The concept of absolute zero will be further refined during the statement of the third law of thermodynamics.

- 1st Law: Energy can neither be created or destroyed
- 2nd Law: All spontaneous events act to increase total entropy
- 3rd Law: Absolute zero is removal of all thermal molecular motion

6.9 NOTE

Reservoirs are systems of large quantity of matter which no temperature difference will occur when finite amount of heat is transferred or removed. Ex- Ocean, lake, air and etc....

6.10 Clausius Theorem

Clausius theorem states that any reversible process can be replaced by a combination of reversible isothermal and adiabatic processes.

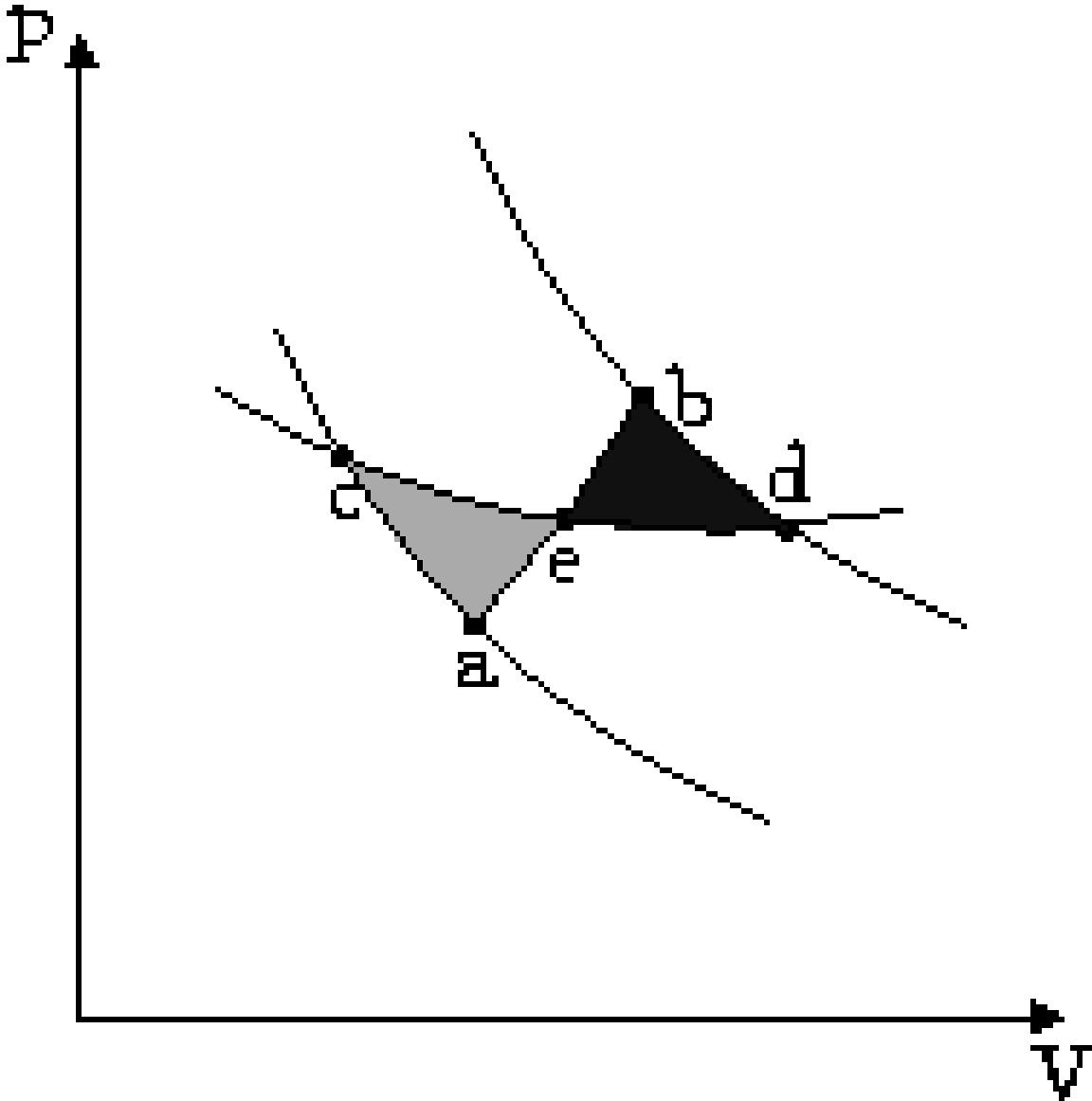


Figure 20 Clausius Theorem

Consider a reversible process $a-b$. A series of isothermal and adiabatic processes can replace this process if the heat and work interaction in those processes is the same as that in the process $a-b$. Let this process be replaced by the process $a-c-d-b$, where $a-c$ and $d-b$ are reversible adiabatic processes, while $c-d$ is a reversible isothermal process. The isothermal line is chosen such that the area $a-e-c$ is the same as the area $b-e-d$. Now, since the area under the $p-V$ diagram is the work done for a reversible process, we have, the total work done in the cycle $a-c-d-b-a$ is zero. Applying the first law, we have, the total heat transferred is also zero as the process is a cycle. Since $a-c$ and $d-b$ are adiabatic processes, the heat transferred in process $c-d$ is the same as that in the process $a-b$. Now applying first law between the states a and b along $a-b$ and $a-c-d-b$, we have, the work done is the same. Thus the heat and work in the process $a-b$ and $a-c-d-b$ are the same and any reversible process $a-b$ can be replaced with a combination of isothermal and adiabatic processes, which is the Clausius theorem.

A corollary of this theorem is that any reversible cycle can be replaced by a series of Carnot cycles.

Suppose each of these Carnot cycles absorbs heat dQ_1^i at temperature T_1^i and rejects heat dQ_2^i at T_2^i . Then, for each of these engines, we have $dQ_1^i/dQ_2^i = -T_1^i/T_2^i$. The negative sign is included as the heat lost from the body has a negative value. Summing over a large number of these cycles, we have, in the limit,

$$\oint_R \frac{dQ}{T} = 0$$

This means that the quantity dQ/T is a property. It is given the name *entropy*.

Further, using Carnot's principle, for an irreversible cycle, the efficiency is less than that for the Carnot cycle, so that

$$\eta_{irr} = 1 - \frac{dQ_2}{dQ_1} < \eta_{Carnot}$$

$$\frac{dQ_1}{T_1} - \frac{dQ_2}{T_2} < 0$$

As the heat is transferred out of the system in the second process, we have, assuming the normal conventions for heat transfer,

$$\frac{dQ_1}{T_1} + \frac{dQ_2}{T_2} < 0$$

So that, in the limit we have,

$$\oint_I \frac{dQ}{T} < 0$$

$$\oint \frac{dQ}{T_{reservoir}} \leq 0$$

The above inequality is called the *inequality of Clausius*. Here the equality holds in the reversible case.

6.11 Entropy

Entropy is the quantitative statement of the second law of thermodynamics. It is represented by the symbol S , and is defined by

$$dS \equiv \left(\frac{dQ}{T} \right)_{rev}$$

Thus, we can calculate the entropy change of a reversible process by evaluating the Note that as we have used the Carnot cycle, the temperature is the reservoir temperature. However, for a reversible process, the system temperature is the same as the reversible temperature.

Consider a system undergoing a cycle 1-2-1, where it returns to the original state along a different path. Since entropy of the system is a property, the change in entropy of the system in 1-2 and 2-1 are numerically equal. Suppose reversible heat transfer takes place in process 1-2 and irreversible heat transfer takes place in process 2-1. Applying Clausius's inequality, it is easy to see that the heat transfer in process 2-1 dQ_{irr} is less than $T dS$. That is, in an irreversible process the same change in entropy takes place with a lower heat transfer. As a corollary, the change in entropy in any process, dS , is related to the heat transfer dQ as

$$dS \geq dQ/T$$

For an isolated system, $dQ = 0$, so that we have

$$dS_{\text{isolated}} \geq 0$$

This is called the *principle of increase of entropy* and is an alternative statement of the second law.

Further, for the whole universe, we have

$$\Delta S = \Delta S_{\text{sys}} + \Delta S_{\text{surr}} > 0$$

For a reversible process,

$$\Delta S_{\text{sys}} = (Q/T)_{\text{rev}} = -\Delta S_{\text{surr}}$$

So that

$$\Delta S_{\text{universe}} = 0$$

for a reversible process.

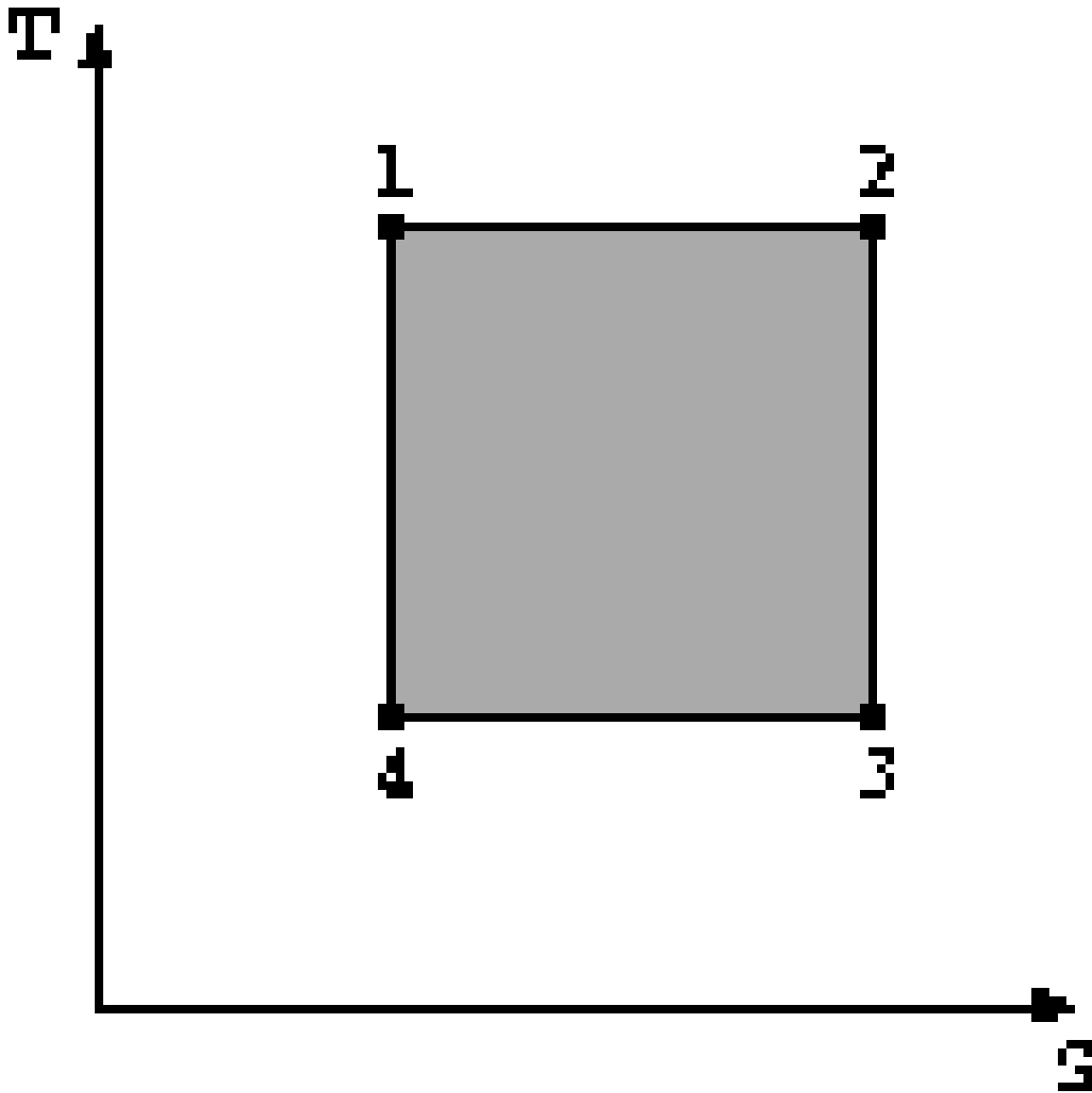


Figure 21 T-S diagram for Carnot Cycle

Since T and S are properties, you can use a T - S graph instead of a p - V graph to describe the change in the system undergoing a reversible cycle. We have, from the first law, $dQ + dW = 0$. Thus the area under the T - S graph is the work done by the system. Further, the reversible adiabatic processes appear as vertical lines in the graph, while the reversible isothermal processes appear as horizontal lines.

6.11.1 Entropy for an Ideal Gas

An ideal gas obeys the equation $pv = RT$. According to the first law,

$$dQ + dW = dU$$

For a reversible process, according to the definition of entropy, we have

$$dQ = T dS$$

Also, the work done is the pressure volume work, so that

$$dW = -p dV$$

The change in internal energy:

$$dU = m c_v dT$$

$$T dS = p dV + m c_v dT$$

Taking per unit quantities and applying ideal gas equation,

$$ds = R dV/v + c_v dT/T$$

$$\Delta s = R \ln \frac{v_2}{v_1} + c_v \ln \frac{T_2}{T_1}$$

As a general rule, all things being equal, entropy increases as, temperature increases and as pressure and concentration decreases and energy stored as internal energy has higher entropy than energy which is stored as kinetic energy.

6.12 Availability

From the second law of thermodynamics, we see that we cannot convert all the heat energy to work. If we consider the aim of extracting useful work from heat, then only some of the heat energy is available to us. It was previously said that an engine working with a reversible cycle was more efficient than an irreversible engine. Now, we consider a system which interacts with a reservoir and generates work, *i.e.*, we look for the maximum work that can be extracted from a system given that the surroundings are at a particular temperature.

Consider a system interacting with a reservoir and doing work in the process. Suppose the system changes state from 1 to 2 while it does work. We have, according to the first law,

$$dQ - dW = dE,$$

where dE is the change in the internal energy of the system. Since it is a property, it is the same for both the reversible and irreversible process. For an irreversible process, it was shown in a previous section that the heat transferred is less than the product of temperature and entropy change. Thus the work done in an irreversible process is lower, from first law.

6.12.1 Availability Function

The availability function is given by Φ , where

$$\Phi \equiv E - T_0 S$$

where T_0 is the temperature of the reservoir with which the system interacts. The availability function gives the effectiveness of a process in producing useful work. The above definition is useful for a non-flow process. For a flow process, it is given by

$$\Psi \equiv H - T_0 S$$

6.12.2 Irreversibility

Maximum work can be obtained from a system by a reversible process. The work done in an actual process will be smaller due to the irreversibilities present. The difference is called the *irreversibility* and is defined as

$$I \equiv W_{\text{rev}} - W$$

From the first law, we have

$$W = \Delta E - Q$$

$$I = \Delta E - Q - (\Phi_2 - \Phi_1)$$

As the system interacts with surroundings of temperature T_0 , we have

$$\Delta S_{\text{surr}} = Q/T_0$$

Also, since

$$E - \Phi = T_0 \Delta S_{\text{sys}}$$

we have

$$I = T_0 (\Delta S_{\text{sys}} + \Delta S_{\text{surr}})$$

Thus,

$$I \geq 0$$

I represents increase in unavailable energy.

6.12.3 Helmholtz and Gibbs Free Energies

Helmholtz Free Energy is defined as

$$F \equiv U - TS$$

The Helmholtz free energy is relevant for a non-flow process. For a flow process, we define the *Gibbs Free Energy*

$$G \equiv H - TS$$

The Helmholtz and Gibbs free energies have applications in finding the conditions for equilibrium.

Category:Engineering Thermodynamics¹

¹ <http://en.wikibooks.org/wiki/Category%3AEngineering%20Thermodynamics>

7 Third Law

7.1 Third Law of Thermodynamics

The Third Law of Thermodynamics extends the definition of Entropy:

Entropy is zero only in a *perfect crystal* at absolute zero (0 kelvin [- 273.15 degree Celsius]).

The Third Law of Thermodynamics can mathematically be expressed as

$$\lim_{T \rightarrow 0} S = 0 \quad (1)$$

where

S = entropy (J/K)

T = absolute temperature (K)

At a temperature of absolute zero there is no thermal energy or heat. At a temperature of zero Kelvin the atoms in a pure crystalline substance are aligned perfectly and do not move. There is no entropy of mixing since the substance is pure. By -VBM

Category:Engineering Thermodynamics¹

¹ <http://en.wikibooks.org/wiki/Category%3AEngineering%20Thermodynamics>

8 Applications

8.1 One Component Systems

All materials can exist in three phases: *solid*¹ , *liquid*² , and *gas*³ . All one component systems share certain characteristics, so that a study of a typical one component system will be quite useful.

1 <http://en.wikipedia.org/wiki/solid>
2 <http://en.wikipedia.org/wiki/liquid>
3 <http://en.wikipedia.org/wiki/gas>

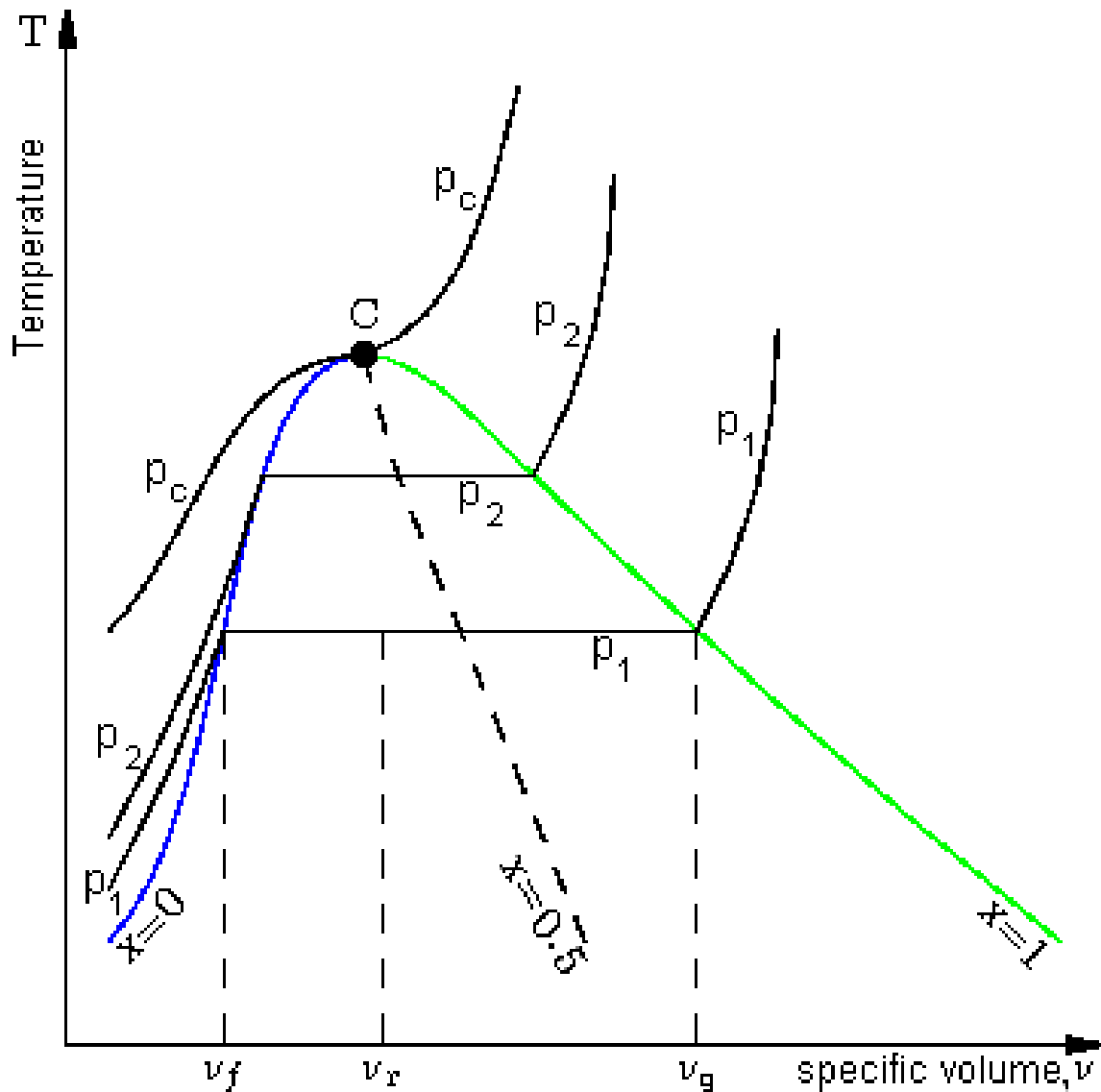


Figure 22 One Component System

For this analysis, we consider heat transferred to the substance at constant pressure. The above chart shows temperature vs. specific volume ($1/\text{density}$) curves for at three different constant pressures. The three line-curves labeled p_1 , p_2 , and p_c above are isobars, showing conditions at constant pressure. When the liquid and vapor coexist, it is called a saturated state. There is no change in temperature or pressure when liquid and vapor are in equilibrium, so that the temperature is called *saturation temperature* and the pressure is called *saturation pressure*. Saturated states are represented by the horizontal lines in the chart. In the temperature range where both liquid and vapor of a pure substance can coexist in equilibrium, for every value of saturated temperature, there is only one corresponding value of saturation pressure. If the temperature of the liquid is lower than the saturation temperature, it is called *subcooled liquid*. If the temperature of the vapor or gas is greater than the saturation temperature it is called *superheated vapor*.

The amount of liquid and vapor in a saturated mixture is specified by its *quality* x , which is the fraction of vapor in the mixture. Thus, the horizontal line representing the vaporization of the fluid has a quality of $x=0$ at the left endpoint where it is 100% liquid and a quality of $x=1$ at the right endpoint where it is 100% vapor. The blue curve in the preceding diagram shows saturation temperatures for saturated liquid i. e. where $x=0$. The green curve in the diagram shows saturation temperatures for saturated vapor i. e. where $x=1$. These curves are not isobars.

$$x = \frac{m_g}{m_f + m_g}$$

$$v_x = (1 - x)v_f + xv_g$$

$$v_{fg} = v_g - v_f$$

If you also consider the solid state, then we get the phase diagram for the material. The point where the solid, liquid, and the vapor state exist in equilibrium is called the *triple point*. Note that as the saturation temperatures increase, the liquid and vapor specific volumes approach each other until the blue and green curves come together and meet at point C on the p_c isobar. At that point C, called the *critical point*, the liquid and vapor states merge together and all their thermodynamic properties become the same. The critical point has a certain temperature T_c , and pressure p_c , which depend on the substance in question. At temperatures above the critical point, the substance is considered a superheated gas.

This diagram is based on the diagram for water. Other pure (one-component) substances have corresponding temperature vs. specific volume diagrams which are fairly similarly shaped, but the temperatures, pressures, and specific volumes will vary.

The thermodynamic properties of materials are given in charts. One commonly used chart is the *Mollier Chart*⁴, which is the plot of enthalpy⁵ versus entropy⁶. The pressure enthalpy chart is frequently used in refrigeration applications. Charts such as these are useful because many processes are isenthalpic, so obtaining values would be as simple as drawing a straight line on the chart and reading off the data.

Steam tables give the values of specific volume, enthalpy, entropy, and internal energy for different temperatures for water. They are of great use to an engineer, with applications in steam turbines, steam engines, and air conditioning, among others.

Gas tables give the same equations for common gases like air. Although most gases roughly obey the ideal gas equation, gas tables note the actual values which are more accurate in many cases. They are not as important as steam tables, but in many cases it is much easier to lookup from a table rather than compute answers.

8.1.1 Gibbs Phase Rule

Gibbs phase rule states that for a heterogeneous system in equilibrium with C components in P phases, the degree of freedom $F = C - P + 2$. Thus, for a one component system with

4 <http://en.wikipedia.org/wiki/Mollier%20Chart>

5 <http://en.wikipedia.org/wiki/enthalpy>

6 <http://en.wikipedia.org/wiki/entropy>

two phases, there is only one degree of freedom. $F=1-2+2$ $F=1$ That is, if you are given either the pressure or temperature of wet steam, you can obtain all the properties, while for superheated steam, which has just one phase, you will need both the pressure and the temperature.

8.2 Psychrometry

Psychrometry is the study of air and water vapor mixtures for air conditioning. For this application, air is taken to be a mixture of nitrogen and oxygen with the other gases being small enough so that they can be approximated by more of nitrogen and oxygen without much error. In this psychrometry section, vapor refers to water vapor. For air at normal (atmospheric) pressure, the saturation pressure of vapor is very low. Also, air is far away from its critical point in those conditions. Thus, the air vapor mixture behaves as an ideal gas mixture. If the partial pressure of the vapor is smaller than the saturation pressure for water for that temperature, the mixture is called unsaturated. The amount of moisture in the air vapor mixture is quantified by its *humidity*.

The absolute humidity ω is the ratio of masses of the vapor and air, *i.e.*, $\omega = m_v/m_a$. Now, applying ideal gas equation, $pV = mRT$ for water vapor and for air, we have, since the volume and temperature are the same, $\omega = 0.622 p_v/p_a$. The ratio of specific gas constants (R in preceding equation) of water vapor to air equals 0.622.

The *relative humidity* ϕ is the ratio of the vapor pressure to the saturation vapor pressure at that temperature, *i.e.*, $\phi = p_v/p_{v,\text{sat}}$.

The *saturation ratio* is the ratio of the absolute humidity to the absolute humidity at saturation, or, $\psi = \omega/\omega_{\text{sat}}$. It is easy to see that the saturation ratio is very close to the value of relative humidity.

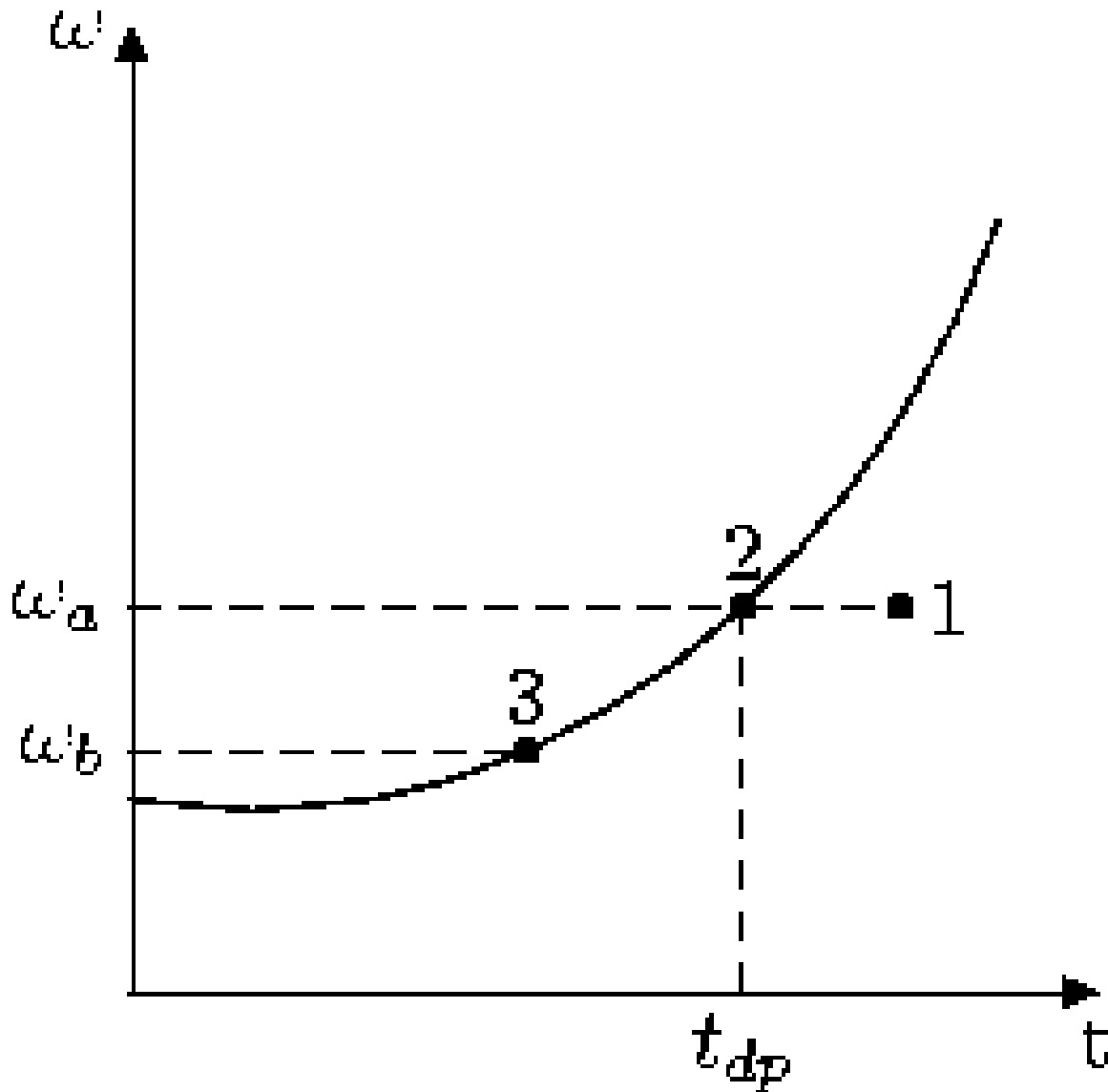


Figure 23 Absolute Humidity

The above plot shows the value of absolute humidity versus the temperature. The initial state of the mixture is 1, and it is cooled isobarically, and at constant absolute humidity. When it reaches 2, it is saturated, and its absolute humidity is ω_a . Further cooling causes condensation and the system moves to point 3, where its absolute humidity is ω_b . The temperature at 2 is called the *dew point*.

It is customary to state all quantities in psychrometry per unit mass of dry air. Thus, the amount of air condensed in the above chart when moving from 2 to 3 is $\omega_b - \omega_a$.

8.2.1 Adiabatic Saturation

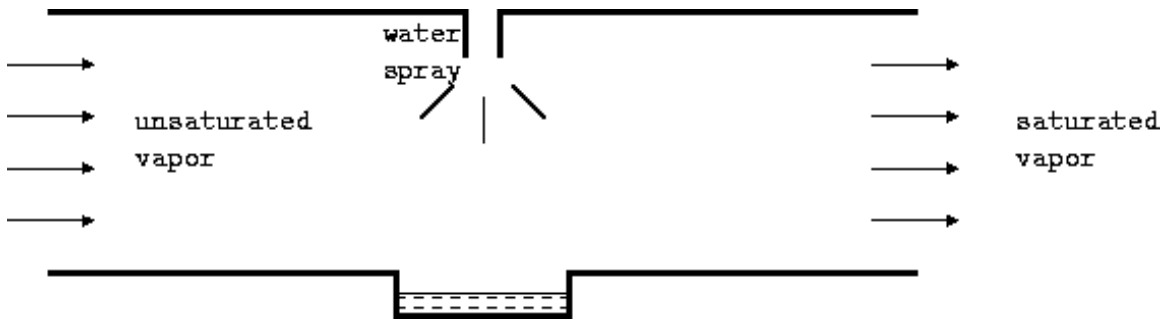


Figure 24 Adiabatic Saturation

Consider an unsaturated mixture entering a chamber. Suppose water was sprayed into the stream, so that the humidity increases and it leaves as a saturated mixture. This is accompanied by a loss of temperature due to heat being removed from the air which is used for vaporization. If the water supplied is at the temperature of exit of the stream, then there is no heat transfer from the water to the mixture. The final temperature of the mixture is called *adiabatic saturation temperature*.

8.2.2 Wet Bulb Temperature

The relative humidity⁷ of air vapor mixtures is measured by using dry and wet bulb thermometers⁸. The dry bulb thermometer is an ordinary thermometer, while the wet bulb thermometer has its bulb covered by a moist wick⁹. When the mixture flows past the two thermometers, the dry bulb thermometer shows the temperature of the stream, while water evaporates from the wick and its temperature falls. This temperature is very close to the adiabatic¹⁰ saturation¹¹ temperature if we neglect the heat transfer due to convection¹².

⁷ <http://en.wikipedia.org/wiki/humidity>

⁸ <http://en.wikipedia.org/wiki/thermometers>

⁹ <http://en.wikipedia.org/wiki/wick>

¹⁰ <http://en.wikipedia.org/wiki/adiabatic>

¹¹ <http://en.wikipedia.org/wiki/saturation>

¹² <http://en.wikipedia.org/wiki/convection>

8.2.3 Psychrometric Chart

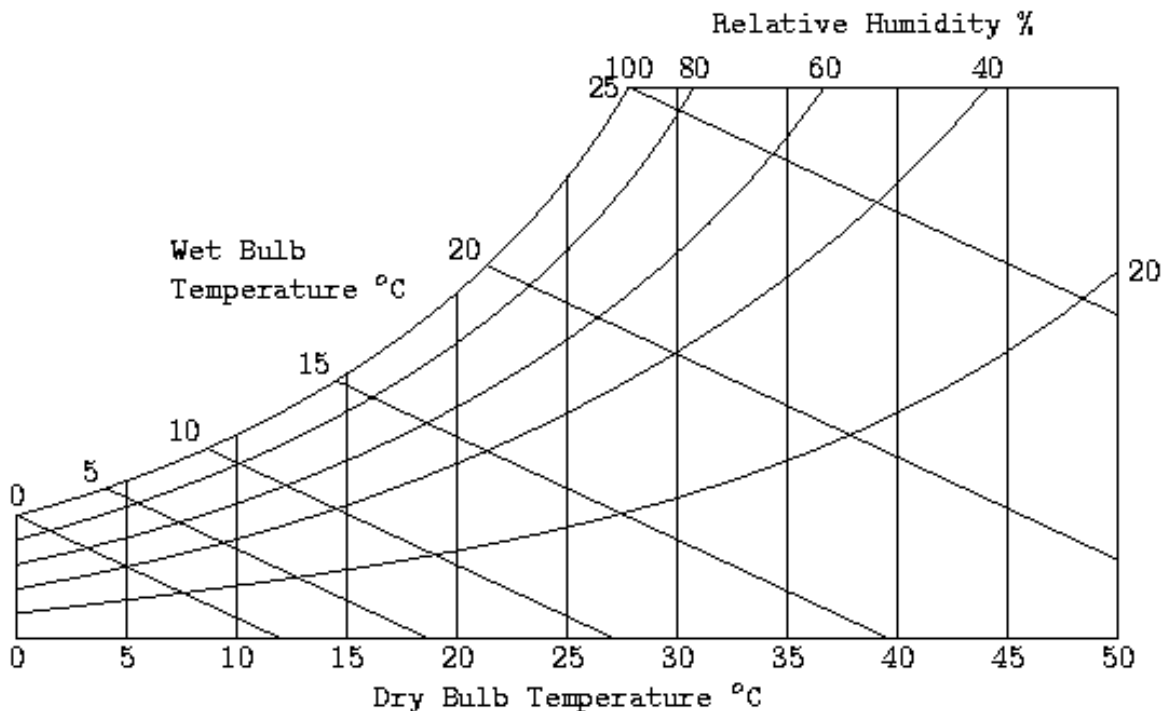


Figure 25 Psychrometric Chart

This chart gives the value of absolute humidity¹³ versus temperature, along with the enthalpy¹⁴. From this chart you can determine the relative humidity given the dry and wet bulb temperatures. We have, from the first law, that for a flow system with no heat transfer, the enthalpy is a constant. Now, for the adiabatic¹⁵ saturation¹⁶ process, there is no heat transfer taking place, so that the adiabatic saturation lines are the same as the wet bulb temperature and the constant enthalpy lines.

Questions

1. The temperature at Phoenix¹⁷ is 35°C with a relative humidity of 40%. Can a room be cooled using a conventional air cooler?

We need to find the wet bulb temperature for the point $T = 35^\circ\text{C}$ and $\varphi = 40\%$. We have, from the psychrometric chart, the wet bulb temperature is between 20 and 25°C. Thus, you can cool the room down to a comfortable temperature using an evaporative cooler.

2. The temperature of Los Angeles¹⁸ is 37°C with relative humidity of 83%. To what temperature can a room be cooled using a conventional air cooler?

¹³ <http://en.wikipedia.org/wiki/humidity>

¹⁴ <http://en.wikipedia.org/wiki/enthalpy>

¹⁵ <http://en.wikipedia.org/wiki/adiabatic>

¹⁶ <http://en.wikipedia.org/wiki/saturation>

¹⁷ <http://en.wikipedia.org/wiki/Phoenix>

¹⁸ <http://en.wikipedia.org/wiki/Los%20Angeles>

The wet bulb temperature is about 34.2°C for this situation. Thus, you cannot use an ordinary cooler to reduce room temperature in this situation. You will need to use an air conditioner.

8.2.4 Air Conditioning

The human body can work efficiently only in a narrow range of conditions. Further, it rejects about 60 W of heat continuously into the surroundings, and more during heavy exercise. The temperature of the body is maintained by the evaporation of sweat from the body. Thus, for comfort, both the temperature and the relative humidity should be low.

Conventional air conditioning consists of setting the humidity at an acceptable level, while reducing the temperature. Reducing the humidity to zero is not the ideal objective. For instance, low humidity leads to issues like high chances of static electricity building up, leading to damage of sensitive electronic equipment. A humidity level of 50% is more acceptable in this case.

The most common method of reducing humidity is to cool the air using a conventional air conditioner working on a reversed Carnot cycle. The vapor that condenses is removed. Now, the air that is produced is very cold, and needs to be heated back up to room temperature before it is released back to the air conditioned area.

8.3 Common Thermodynamic Cycles

Several thermodynamic cycles used in machines can be approximated with idealized cycles. It was shown previously that a Carnot engine was the most efficient engine operating between two thermal reservoirs. However, due to practical difficulties, Carnot cycle cannot be implemented in all situations. The following sections deal with idealized (non Carnot) systems found in practice.

8.3.1 Rankine Cycle

In the Rankine cycle, also called the *standard vapor power cycle*, the working fluid follows a closed cycle. We will consider water as a working substance. In the Rankine cycle, water is pumped from a low pressure to a high pressure using a liquid pump. This water is then heated in the boiler at constant pressure where its temperature increases and it is converted to superheated vapor. This vapor is then expanded in an expander to generate work. This expander can be a turbine or a reciprocating (i.e. piston) machine such as those used in older steam locomotive or ship. The output of the expander is then cooled in a condenser to the liquid state and fed to the pump. The Rankine cycle differs from the Carnot cycle in that the input to the pump is a liquid (it is cooled more in the condenser). This allows the use of a small, low power pump due to the lower specific volume of liquid compared to steam. Also, the heat transfer in the boiler takes place mainly as a result of a phase change, compared to the isothermal heating of the ideal gas in the Carnot cycle, so that the efficiency is quite good (even though it is still lower than the Carnot efficiency). The amount of heat transferred as the liquid is heated to its boiling point is very small compared

to the heat transfer during phase change. The steam is superheated so that no liquid state exists inside the turbine. Condensation in the turbine can be devastating as it can cause corrosion and erosion of the blades.

There are several modifications to the Rankine cycle leading to even better practical designs. In the *reheat cycle* there are two expanders working in series, and the steam from the high pressure stage is heated again in the boiler before it enters the low pressure expander. This avoids the problem of moisture in the turbine and also increases the efficiency. The *regenerative cycle* is another modification to increase the efficiency of the Rankine cycle. In many Rankine cycle implementations, the water enters the boiler in the subcooled state, and also, the large difference in temperature between the one at which heat is supplied to the boiler and the fluid temperature will give rise to irreversibilities which will cause the efficiency to drop. In the regenerative cycle, the output of the condenser is heated by some steam tapped from the expander. This causes the overall efficiency to increase, due to the reasons noted above.

8.3.2 Otto Cycle

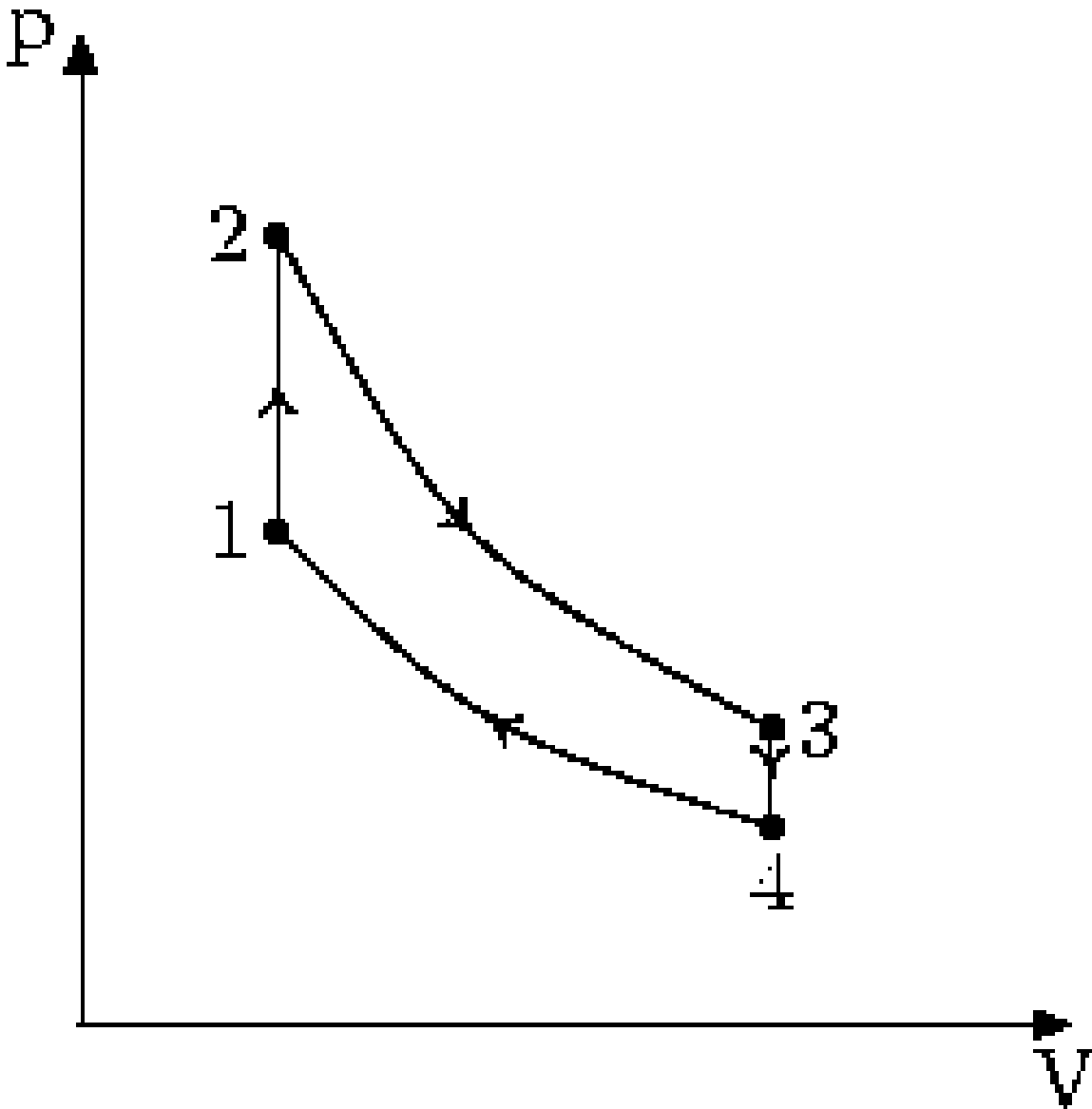


Figure 26 Otto Cycle

The *Otto Cycle* is the idealization for the process found in the reciprocating internal combustion engines which are used by most automobiles. While in an actual engine the gas is released as exhaust, this is found to be a good way to analyze the process. There are, of course, other losses too in the actual engine. For instance, partial combustion and aspiration problems for a high speed engine. The working material in the idealized cycle is an ideal gas, as opposed to the air fuel mixture in an engine.

1. Heat is transferred at constant volume during 1-2.
2. The gas expands reversibly and adiabatically during 2-3, where work is done.
3. Heat is rejected at constant volume at low temperature during 3-4.
4. The gas is compressed reversibly and adiabatically in 4-1.

Analysis

Heat is transferred at constant volume in 1-2, so that $Q_{1-2} = m c_v(T_2 - T_1)$. Similarly, the heat rejected in 3-4 is $Q_{3-4} = m c_v(T_3 - T_4)$. The thermal efficiency of the Otto cycle is thus

$$\eta_{th} = (Q_{1-2} - Q_{3-4})/Q_{1-2}$$

$$\eta_{th} = 1 - Q_{3-4}/Q_{1-2}$$

$$\eta_{th} = 1 - (T_3 - T_4)/(T_2 - T_1)$$

Since 2-3 and 4-1 are reversible adiabatic processes involving an ideal gas, we have,

$$T_2/T_3 = (V_3/V_2)^{\gamma - 1}$$

and

$$T_4/T_1 = (V_1/V_4)^{\gamma - 1}$$

But,

$$V_1 = V_2$$

and

$$V_3 = V_4$$

So, we have

$$T_2/T_3 = T_1/T_4$$

Thus,

$$\eta_{th} = 1 - (T_3/T_2)(1 - T_4/T_3)/(1 - T_1/T_2)$$

Or

$$\eta_{th} = 1 - T_3/T_2$$

If we introduce the term $r_c = V_3/V_2$ for the compression ratio, then we have,

$$\eta_{th} = 1 - r_c^{1 - \gamma}$$

As can be seen, increasing the compression ratio will improve thermal efficiency. However, increasing the compression ratio causes the peak temperature to go up, which may cause spontaneous, uncontrolled ignition of the fuel, which leads to a shock wave traveling through the cylinder, and is called *knocking* .

8.3.3 Diesel Cycle

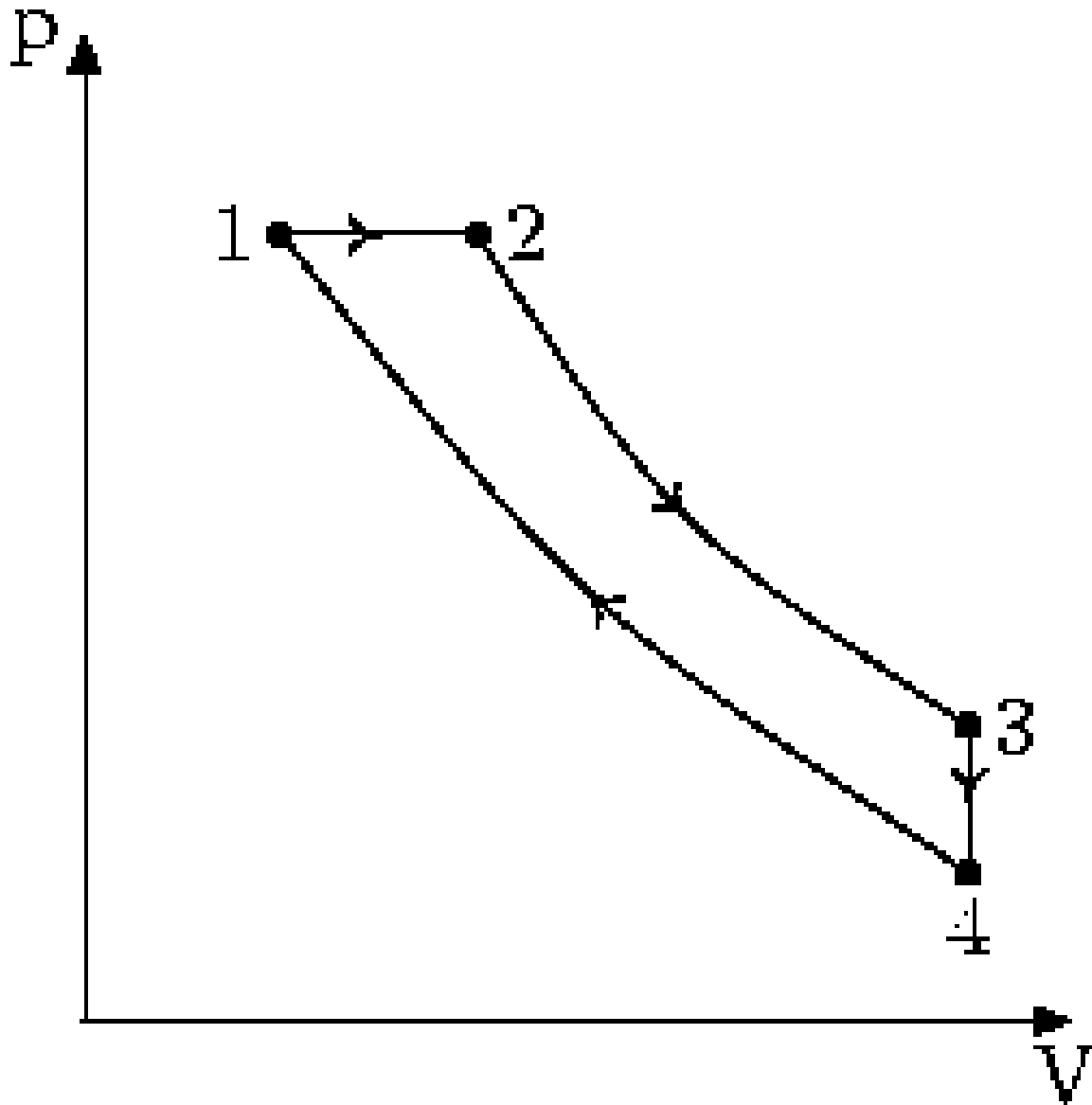


Figure 27 Diesel Cycle

The Diesel cycle is the idealized cycle for compression ignition engines (ones that don't use a spark plug). The difference between the Diesel cycle and the Otto cycle is that heat is supplied at constant pressure.

1. Heat is supplied reversibly at constant pressure in 1-2.
2. Reversible adiabatic expansion during which work is done in 2-3.
3. Heat is rejected reversibly at constant volume in 3-4.
4. Gas is compressed reversibly and adiabatically in 4-1.

Analysis

Heat is transferred to the system at constant pressure during 1-2 so that

$$Q_{\text{in}} = m c_p (T_2 - T_1)$$

Heat is rejected by the system at constant volume during 3-4:

$$Q_{\text{out}} = m c_v (T_3 - T_4)$$

Thus, the efficiency of the Diesel cycle is

$$\eta_{th} = (Q_{\text{in}} - Q_{\text{out}})/Q_{\text{in}}$$

$$\eta_{th} = 1 - Q_{\text{out}}/Q_{\text{in}}$$

$$\eta_{th} = 1 - (c_v (T_3 - T_4))/(c_p (T_2 - T_1))$$

$$\eta_{th} = 1 - (1/\gamma) (T_3 - T_4)/(T_2 - T_1)$$

$$\eta_{th} = 1 - \frac{1}{\gamma} \frac{T_4}{T_1} \left(\frac{\frac{T_3}{T_4} - 1}{\frac{T_2}{T_1} - 1} \right)$$

We define the cutoff ratio as $r_t = V_2/V_1$, and since the pressures at 1 and 2 are equal, we have, applying the ideal gas equation, $T_2/T_1 = r_t$. Now, for the adiabatic processes 2-3 and 4-1 we have,

$$\frac{T_2}{T_3} = \left(\frac{V_3}{V_2} \right)^{\gamma-1}$$

$$\frac{T_1}{T_4} = \left(\frac{V_4}{V_1} \right)^{\gamma-1}$$

Since $V_3 = V_4$, we have

$$\frac{T_2}{T_1} \frac{T_4}{T_3} = \left(\frac{V_1}{V_2} \right)^{\gamma-1}$$

$$\frac{T_4}{T_3} = \left(\frac{V_1}{V_2} \right)^{\gamma}$$

$$\eta_{th} = 1 - \frac{1}{\gamma} \frac{1}{r_c^{\gamma-1}} \left(\frac{r_t^{\gamma}-1}{r_t-1} \right)$$

8.3.4 Dual Cycle

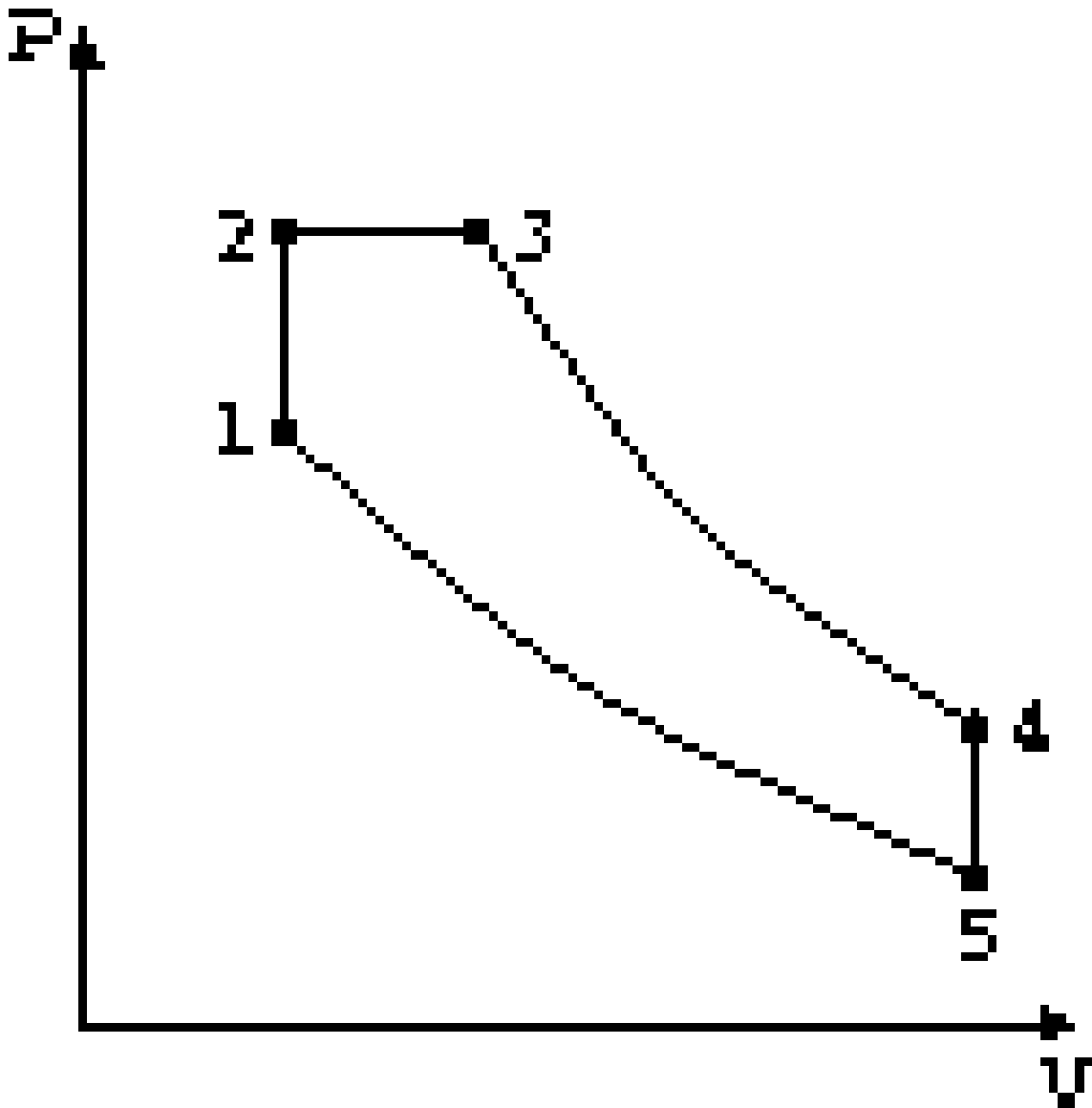


Figure 28 Dual Cycle

The dual cycle is sometimes used to approximate actual cycles as the time taken for heat transfer in the engine is not zero for the Otto cycle (so not constant volume). In the Diesel cycle, due to the nature of the combustion process, the heat input does not occur at constant pressure.

8.3.5 Gas Turbine Cycle (or Joule-Brayton Cycle)

Gas turbines are rotary internal combustion engines. As the first stage air is drawn in from outside and compressed using a compressor. Then the fuel is introduced and the mixture

is ignited in the combustion chamber. The hot gases are expanded using a turbine which produces work. The output of the turbine is vented outside as exhaust.

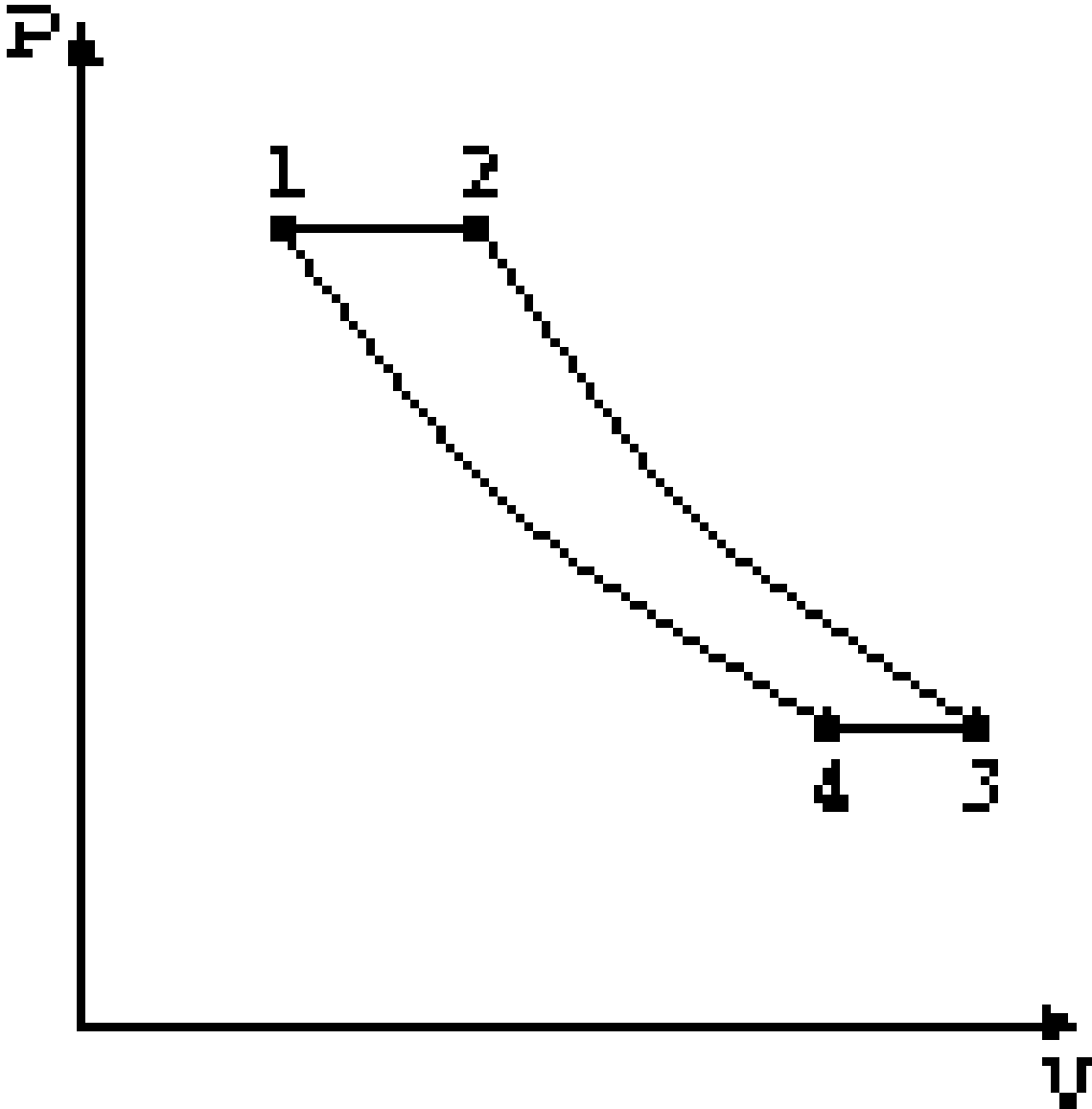


Figure 29 Gas Turbine Cycle

The ideal gas turbine cycle is shown above. The four stages are

1. Heat input at constant pressure during 1-2.
2. Reversible adiabatic expansion during 2-3, where work is done.
3. Heat rejection at constant pressure during 3-4.
4. Reversible adiabatic compression during 4-1 where work is consumed.

Large amount of work is consumed in process 4-1 for a gas turbine cycle as the working material (gas) is very compressible. The compressor needs to handle a large volume and achieve large compression ratios.

Analysis

The heat input in a gas turbine cycle is given by $Q_{in} = m c_p (T_2 - T_1)$ and the heat rejected $Q_{out} = m c_p (T_3 - T_4)$. Thus the thermal efficiency is given by

$$\eta_{th} = 1 - \frac{Q_{out}}{Q_{in}}$$

$$\eta_{th} = 1 - \left(\frac{T_3 - T_4}{T_2 - T_1} \right)$$

$$\eta_{th} = 1 - \frac{T_4}{T_1} \left(\frac{\frac{T_3}{T_4} - 1}{\frac{T_2}{T_1} - 1} \right)$$

Since the adiabatic processes take place between the same pressures, the temperature ratios are the same

$$\eta_{th} = 1 - \frac{T_4}{T_1} = 1 - \frac{1}{\left(\frac{p_1}{p_4} \right)^{\frac{\gamma-1}{\gamma}}}$$

Or

$$\eta_{th} = 1 - \frac{1}{r_p^{\frac{\gamma-1}{\gamma}}}$$

Where r_p is the pressure ratio and is a fundamental quantity for the gas turbine cycle.

8.3.6 Refrigeration Cycles

The ideal refrigeration cycle is reverse of Carnot cycle, working as a heat pump instead of as a heat engine. However, there are practical difficulties in making such a system work.

The *gas refrigeration cycle* is used in aircraft to cool cabin air. The ambient air is compressed and then cooled using work from a turbine. The turbine itself uses work from the compressed air, further cooling it. The output of the turbine as well as the air which is used to cool the output of the compressor is mixed and sent to the cabin.

The Rankine vapor-compression cycle is a common alternative to the ideal Carnot cycle. A working material such as Freon or R-134a, called the *refrigerant*, is chosen based on its boiling point and heat of vaporization. The components of a vapor-compression refrigeration system are the compressor, condenser, the expansion (or throttling) valve, and the evaporator. The working material (in gaseous form) is compressed by the compressor, and its output is cooled to a liquid in the condenser. The output of the condenser is throttled to a lower pressure in the throttling valve, and sent to the evaporator which absorbs heat. The gas from the evaporator is sent to the compressor, completing the cycle.

Standard refrigeration units use the throttling valve instead of a turbine to expand the gas as the work output that would be produced is not significant to justify the cost of a turbine. There are irreversibilities associated with such an expansion, but it is cost effective when construction costs are considered.

Category:Engineering Thermodynamics¹⁹

¹⁹ <http://en.wikibooks.org/wiki/Category%3AEngineering%20Thermodynamics>

9 Further Reading

Further reading and resources:

- Sadi Carnot's Ingenious Reasoning of Ideal Heat-Engine Reversible Cycles. WSEAS Press, , 2008 (full text¹)
- Thermodynamics²
- Engineering Thermodynamics - A Graphical Approach³ by Dr. Israel Urieli, Ohio University Dept of Mechanical Engineering

Category:Engineering Thermodynamics⁴

¹ http://www.kostic.niu.edu/energy/WSEAS-EEESD08_588-357Kostic-Sadi%20Carnot%E2%80%99s%20Ingenious%20Reasoning.pdf

² <http://en.wikibooks.org/wiki/Thermodynamics>

³ <http://www.ent.ohiou.edu/~thermo/>

⁴ <http://en.wikibooks.org/wiki/Category%3AEngineering%20Thermodynamics>

10 Contributors

Edits	User
2	Adrignola ¹
1	Aleksev ²
1	Avicennasis ³
1	Computer tom ⁴
4	Dan Polansky ⁵
2	Derbeth ⁶
3	Geocachernemesis ⁷
5	H Padleckas ⁸
4	Hacktivist ⁹
1	Herbythyme ¹⁰
4	JAQ ¹¹
12	Jguk ¹²
5	Jomegat ¹³
4	Karl Wick ¹⁴
2	Kayau ¹⁵
1	Liblamb ¹⁶
2	Matiiia ¹⁷
3	Mattb112885 ¹⁸
6	Metric1000 ¹⁹
1	Panic2k4 ²⁰
9	QuiteUnusual ²¹

1	http://en.wikibooks.org/wiki/User:Adrignola
2	http://en.wikibooks.org/wiki/User:Aleksev
3	http://en.wikibooks.org/wiki/User:Avicennasis
4	http://en.wikibooks.org/wiki/User:Computer_tom
5	http://en.wikibooks.org/wiki/User:Dan_Polansky
6	http://en.wikibooks.org/wiki/User:Derbeth
7	http://en.wikibooks.org/wiki/User:Geocachernemesis
8	http://en.wikibooks.org/wiki/User:H_Padleckas
9	http://en.wikibooks.org/wiki/User:Hacktivist
10	http://en.wikibooks.org/wiki/User:Herbythyme
11	http://en.wikibooks.org/wiki/User:JAQ
12	http://en.wikibooks.org/wiki/User:Jguk
13	http://en.wikibooks.org/wiki/User:Jomegat
14	http://en.wikibooks.org/wiki/User:Karl_Wick
15	http://en.wikibooks.org/wiki/User:Kayau
16	http://en.wikibooks.org/wiki/User:Liblamb
17	http://en.wikibooks.org/wiki/User:Matiiia
18	http://en.wikibooks.org/wiki/User:Mattb112885
19	http://en.wikibooks.org/wiki/User:Metric1000
20	http://en.wikibooks.org/wiki/User:Panic2k4
21	http://en.wikibooks.org/wiki/User:QuiteUnusual

9 Recent Runes²²
1 Sigma 7²³
1 Syum90²⁴
1 Webaware²⁵
1 Xania²⁶
1 YMS²⁷

²² http://en.wikibooks.org/wiki/User:Recent_Runes
²³ http://en.wikibooks.org/wiki/User:Sigma_7
²⁴ <http://en.wikibooks.org/wiki/User:Syum90>
²⁵ <http://en.wikibooks.org/wiki/User:Webaware>
²⁶ <http://en.wikibooks.org/wiki/User:Xania>
²⁷ <http://en.wikibooks.org/wiki/User:YMS>

List of Figures

- GFDL: Gnu Free Documentation License. <http://www.gnu.org/licenses/fdl.html>
- cc-by-sa-3.0: Creative Commons Attribution ShareAlike 3.0 License. <http://creativecommons.org/licenses/by-sa/3.0/>
- cc-by-sa-2.5: Creative Commons Attribution ShareAlike 2.5 License. <http://creativecommons.org/licenses/by-sa/2.5/>
- cc-by-sa-2.0: Creative Commons Attribution ShareAlike 2.0 License. <http://creativecommons.org/licenses/by-sa/2.0/>
- cc-by-sa-1.0: Creative Commons Attribution ShareAlike 1.0 License. <http://creativecommons.org/licenses/by-sa/1.0/>
- cc-by-2.0: Creative Commons Attribution 2.0 License. <http://creativecommons.org/licenses/by/2.0/>
- cc-by-2.0: Creative Commons Attribution 2.0 License. <http://creativecommons.org/licenses/by/2.0/deed.en>
- cc-by-2.5: Creative Commons Attribution 2.5 License. <http://creativecommons.org/licenses/by/2.5/deed.en>
- cc-by-3.0: Creative Commons Attribution 3.0 License. <http://creativecommons.org/licenses/by/3.0/deed.en>
- GPL: GNU General Public License. <http://www.gnu.org/licenses/gpl-2.0.txt>
- LGPL: GNU Lesser General Public License. <http://www.gnu.org/licenses/lgpl.html>
- PD: This image is in the public domain.
- ATTR: The copyright holder of this file allows anyone to use it for any purpose, provided that the copyright holder is properly attributed. Redistribution, derivative work, commercial use, and all other use is permitted.
- EURO: This is the common (reverse) face of a euro coin. The copyright on the design of the common face of the euro coins belongs to the European Commission. Authorised is reproduction in a format without relief (drawings, paintings, films) provided they are not detrimental to the image of the euro.
- LFK: Lizenz Freie Kunst. <http://artlibre.org/licence/lal/de>
- CFR: Copyright free use.

- EPL: Eclipse Public License. <http://www.eclipse.org/org/documents/epl-v10.php>

Copies of the GPL, the LGPL as well as a GFDL are included in chapter Licenses²⁸. Please note that images in the public domain do not require attribution. You may click on the image numbers in the following table to open the webpage of the images in your webbrowser.

²⁸ Chapter 11 on page 69

1	Webaware	
2	Sundance Raphael, Webaware	
3	Az1568, Webaware	
4	Webaware	
5	Az1568, Webaware	
6	Daniele Pugliesi, Emijrpbob, Hazard-Bot, Hidaspal, Jarekt-Bot, MGA73bot2, Mdd, Pieter Kuiper, SchlurcherBot	
7	Webaware	
8	Az1568, Jomegat, Webaware	
9	Webaware	
10		
11		
12		
13		
14	Az1568, Webaware	
15		
16		
17		
18		
19	Az1568, Webaware	
20	Stryn, Sundance Raphael, Webaware	
21	Webaware	
22	Az1568, H Padleckas	
23	Darklama, Webaware	
24	Adrignola, Az1568, ViperSnake151, Webaware	
25	Az1568, ViperSnake151, Webaware	
26	Az1568, Webaware	
27	Az1568, Webaware	
28	Az1568, Webaware	
29	Darklama, Webaware	

11 Licenses

11.1 GNU GENERAL PUBLIC LICENSE

Version 3, 29 June 2007

Copyright © 2007 Free Software Foundation, Inc. <<http://fsf.org/>>

Everyone is permitted to copy and distribute verbatim copies of this license document, but changing it is not allowed. Preamble

The GNU General Public License is a free, copyleft license for software and other kinds of works.

The licenses for most software and other practical works are designed to take away your freedom to share and change the works. By contrast, the GNU General Public License is intended to guarantee your freedom to share and change all versions of a program—to make sure it remains free software for all its users. We, the Free Software Foundation, use the GNU General Public License for most of our software; it applies also to any other work released this way by its authors. You can apply it to your programs, too.

When we speak of free software, we are referring to freedom, not price. Our General Public Licenses are designed to make sure that you have the freedom to distribute copies of free software (and charge for them if you wish), that you receive source code or can get it if you want it, that you can change the software or use pieces of it in new free programs, and that you know you can do these things.

To protect your rights, we need to prevent others from denying you these rights or asking you to surrender the rights. Therefore, you have certain responsibilities if you distribute copies of the software, or if you modify it: responsibilities to respect the freedom of others.

For example, if you distribute copies of such a program, whether gratis or for a fee, you must pass on to the recipients the same freedoms that you received. You must make sure that they, too, receive or can get the source code. And you must show them these terms so they know their rights.

Developers that use the GNU GPL protect your rights with two steps: (1) assert copyright on the software, and (2) offer you this License giving you legal permission to copy, distribute and/or modify it.

For the developers' and authors' protection, the GPL clearly explains that there is no warranty for this free software. For both users' and authors' sake, the GPL requires that modified versions be marked as changed, so that their problems will not be attributed erroneously to authors of previous versions.

Some devices are designed to deny users access to install or run modified versions of the software inside them, although the manufacturer can do so. This is fundamentally incompatible with the aim of protecting users' freedom to change the software. The systematic pattern of such abuse occurs in the area of products for individuals to use, which is precisely where it is most unacceptable. Therefore, we have designed this version of the GPL to prohibit the practice for those products. If such problems arise substantially in other domains, we stand ready to extend this provision to those domains in future versions of the GPL, as needed to protect the freedom of users.

Finally, every program is threatened constantly by software patents. States should not allow patents to restrict development and use of software on general-purpose computers, but in those that do, we wish to avoid the special danger that patents applied to a free program could make it effectively proprietary. To prevent this, the GPL assures that patents cannot be used to render the program non-free.

The precise terms and conditions for copying, distribution and modification follow. TERMS AND CONDITIONS 0. Definitions.

"This License" refers to version 3 of the GNU General Public License.

"Copyright" also means copyright-like laws that apply to other kinds of works, such as semiconductor masks.

"The Program" refers to any copyrightable work licensed under this License. Each licensee is addressed as "you". "Licensees" and "recipients" may be individuals or organizations.

To "modify" a work means to copy from or adapt all or part of the work in a fashion requiring copyright permission, other than the making of an exact copy. The resulting work is called a "modified version" of the earlier work or a work "based on" the earlier work.

A "covered work" means either the unmodified Program or a work based on the Program.

To "propagate" a work means to do anything with it that, without permission, would make you directly or secondarily liable for infringement under applicable copyright law, except executing it on a computer or modifying a private copy. Propagation includes copying, distribution (with or without modification), making available to the public, and in some countries other activities as well.

To "convey" a work means any kind of propagation that enables other parties to make or receive copies. Mere interaction with a user through a computer network, with no transfer of a copy, is not conveying.

An interactive user interface displays "Appropriate Legal Notices" to the extent that it includes a convenient and prominently visible feature that (1) displays an appropriate copyright notice, and (2) tells the user that there is no warranty for the work (except to the extent that warranties are provided), that licensees may convey the work under this License, and how to view a copy of this License. If the interface presents a list of user commands or options, such as a menu, a prominent item in the list meets this criterion. 1. Source Code.

The "source code" for a work means the preferred form of the work for making modifications to it. "Object code" means any non-source form of a work.

A "Standard Interface" means an interface that either is an official standard defined by a recognized standards body, or, in the case of interfaces specified for a particular programming language, one that is widely used among developers working in that language.

The "System Libraries" of an executable work include anything, other than the work as a whole, that (a) is included in the normal form of packaging a Major Component, but which is not part of that Major Component, and (b) serves only to enable use of the work with that Major Component, or to implement a Standard Interface for which an implementation is available to the public in source code form. A "Major Component", in this context, means a major operating component (kernel, window system, and so on) of the specific essential system (if any) on which the executable work runs, or a compiler used to produce the work, or an object code interpreter used to run it.

The "Corresponding Source" for a work in object code form means all the source code needed to generate, install, and (for an executable work) run the object code and to modify the work, including scripts to control those activities. However, it does not include the work's System Libraries, or general-purpose tools or generally available free programs which are used unmodified in performing those activities but which are not part of the work. For example, Corresponding Source includes interface definition files associated with source files for the work, and the source code for shared libraries and dynamically linked subprograms that the work is specifically designed to require, such as by intimate data communication or control flow between those subprograms and other parts of the work.

The Corresponding Source need not include anything that users can regenerate automatically from other parts of the Corresponding Source.

The Corresponding Source for a work in source code form is that same work. 2. Basic Permissions.

All rights granted under this License are granted for the term of copyright on the Program, and are irrevocable provided the stated conditions are met. This License explicitly affirms your unlimited permission to run the unmodified Program. The output from running a covered work is covered by this License only if the output, given its content, constitutes a covered work. This License acknowledges your rights of fair use or other equivalent, as provided by copyright law.

You may make, run and propagate covered works that you do not convey, without conditions so long as your license otherwise remains in force. You may convey covered works to others for the sole purpose of having them make modifications exclusively for you, or provide you with facilities for running those works, provided that you comply with the terms of this License in conveying all material for which you do not control copyright. Those thus making or running the covered works for you must do so exclusively on your behalf, under your direction and control, on terms that prohibit them from making any copies of your copyrighted material outside their relationship with you.

Conveying under any other circumstances is permitted solely under the conditions stated below. Sublicensing is not allowed; section 10 makes it unnecessary. 3. Protecting Users' Legal Rights From Anti-Circumvention Law.

No covered work shall be deemed part of an effective technological measure under any applicable law fulfilling obligations under article 11 of the WIPO copyright treaty adopted on 20 December 1996, or similar laws prohibiting or restricting circumvention of such measures.

When you convey a covered work, you waive any legal power to forbid circumvention of technological measures to the extent such circumvention is effected by exercising rights under this License with respect to the covered work, and you disclaim any intention to limit operation or modification of the work as a means of enforcing, against the work's users, your or third parties' legal rights to forbid circumvention of technological measures. 4. Conveying Verbatim Copies.

You may convey verbatim copies of the Program's source code as you receive it, in any medium, provided that you conspicuously and appropriately publish on each copy an appropriate copyright notice; keep intact all notices stating that this License and any non-permissive terms added in accord with section 7 apply to the code; keep intact all notices of the absence of any warranty; and give all recipients a copy of this License along with the Program.

You may charge any price or no price for each copy that you convey, and you may offer support or warranty protection for a fee. 5. Conveying Modified Source Versions.

You may convey a work based on the Program, or the modifications to produce it from the Program, in the form of source code under the terms of section 4, provided that you also meet all of these conditions:

* a) The work must carry prominent notices stating that you modified it, and giving a relevant date. * b) The work must carry prominent notices stating that it is released under this License and any conditions added under section 7. This requirement modifies the requirement in section 4 to "keep intact all notices". * c) You must license the entire work, as a whole, under this License to anyone who comes into possession of a copy. This License will therefore apply, along with any applicable section 7 additional terms, to the whole of the work, and all its parts, regardless of how they are packaged. This License gives no permission to license the work in any other way, but it does not invalidate such permission if you have separately received it. * d) If the work has interactive user interfaces, each must display Appropriate Legal Notices; however, if the Program has interactive interfaces that do not display Appropriate Legal Notices, your work need not make them do so.

A compilation of a covered work with other separate and independent works, which are not by their nature extensions of the covered work, and which are not combined with it such as to form a larger program, in or on a volume of a storage or distribution medium, is called an "aggregate" if the compilation and its resulting copyright are not used to limit the access or legal rights of the compilation's users beyond what the individual works permit. Inclusion of a covered work in an aggregate does not cause this License to apply to the other parts of the aggregate. 6. Conveying Non-Source Forms.

You may convey a covered work in object code form under the terms of sections 4 and 5, provided that you also convey the machine-readable Corresponding Source under the terms of this License, in one of these ways:

* a) Convey the object code in, or embodied in, a physical product (including a physical distribution medium), accompanied by the Corresponding Source fixed on a durable physical medium customarily used for software interchange. * b) Convey the object code in, or embodied in, a physical product (including a physical distribution medium), accompanied by a written offer, valid for at least three years and valid for as long as you offer spare parts or customer support for that product model, to give anyone who possesses the object code either (1) a copy of the Corresponding Source for all the software in the product that is covered by this License, on a durable physical medium customarily used for software interchange, for a price no more than your reasonable cost of physically performing this conveying of source, or (2) access to copy the Corresponding Source from a network server at no charge. * c) Convey individual copies of the object code with a copy of the written offer to provide the Corresponding Source. This alternative is allowed only occasionally and noncommercially, and only if you received the object code with such an offer, in accord with subsection 6b. * d) Convey the object code by offering access from a designated place (gratis or for a charge), and offer equivalent access to the Corresponding Source in the same way through the same place at no further charge. You need not require recipients to copy the Corresponding Source along with the object code. If the place to copy the object code is a network server, the Corresponding Source may be on a

different server (operated by you or a third party) that supports equivalent copying facilities, provided you maintain clear directions next to the object code saying where to find the Corresponding Source. Regardless of what server hosts the Corresponding Source, you remain obligated to ensure that it is available for as long as needed to satisfy these requirements. * e) Convey the object code using peer-to-peer transmission, provided you inform other peers where the object code and Corresponding Source of the work are being offered to the general public at no charge under subsection 6d.

A separable portion of the object code, whose source code is excluded from the Corresponding Source as a System Library, need not be included in conveying the object code work.

A "User Product" is either (1) a "consumer product", which means any tangible personal property which is normally used for personal, family, or household purposes, or (2) anything designed or sold for incorporation into a dwelling. In determining whether a product is a consumer product, doubtful cases shall be resolved in favor of coverage. For a particular product received by a particular user, "normally used" refers to a typical or common use of that class of product, regardless of the status of the particular user or of the way in which the particular user actually uses, or expects to be expected to use, the product. A product is a consumer product regardless of whether the product has substantial commercial, industrial or non-consumer uses, unless such uses represent the only significant mode of use of the product.

"Installation Information" for a User Product means any methods, procedures, authorization keys, or other information required to install and execute modified versions of a covered work in that User Product from a modified version of its Corresponding Source. The information must suffice to ensure that the continued functioning of the modified object code is in no case prevented or interfered with solely because modification has been made.

If you convey an object code work under this section in, or with, or specifically for use in, a User Product, and the conveying occurs as part of a transaction in which the right of possession and use of the User Product is transferred to the recipient in perpetuity or for a fixed term (regardless of how the transaction is characterized), the Corresponding Source conveyed under this section must be accompanied by the Installation Information. But this requirement does not apply if neither you nor any third party retains the ability to install modified object code on the User Product (for example, the work has been installed in ROM).

The requirement to provide Installation Information does not include a requirement to continue to provide support service, warranty, or updates for a work that has been modified or installed by the recipient, or for the User Product in which it has been modified or installed. Access to a network may be denied when the modification itself materially and adversely affects the operation of the network or violates the rules and protocols for communication across the network.

Corresponding Source conveyed, and Installation Information provided, in accord with this section must be in a format that is publicly documented (and with an implementation available to the public in source code form), and must require no special password or key for unpacking, reading or copying. 7. Additional Terms.

"Additional permissions" are terms that supplement the terms of this License by making exceptions from one or more of its conditions. Additional permissions that are applicable to the entire Program shall be treated as though they were included in this License, to the extent that they are valid under applicable law. If additional permissions apply only to part of the Program, that part may be used separately under those permissions, but the entire Program remains governed by this License without regard to the additional permissions.

When you convey a copy of a covered work, you may at your option remove additional permissions from that copy, or from any part of it. (Additional permissions may be written to require their own removal in certain cases when you modify the work.) You may place additional permissions on material, added by you to a covered work, for which you have or can give appropriate copyright permission.

Notwithstanding any other provision of this License, for material you add to a covered work, you may (if authorized by the copyright holders of that material) supplement the terms of this License with terms:

* a) Disclaiming warranty or limiting liability differently from the terms of sections 15 and 16 of this License; or * b) Requiring preservation of specified reasonable legal notices or author attributions in that material or in the Appropriate Legal Notices displayed by works containing it; or * c) Prohibiting misrepresentation of the origin of that material, or requiring that modified versions of such material be marked in reasonable ways as different from the original version; or * d) Limiting the use for publicity purposes of names of licensors or authors of the material; or * e) Declining to grant rights under trademark law for use of some trade names, trademarks, or service marks; or * f) Requiring indemnification of licensors and authors of that material by anyone who conveys the material (or modified versions of it) with contractual assumptions of liability to the recipient, for any liability that these contractual assumptions directly impose on those licensors and authors.

All other non-permissive additional terms are considered "further restrictions" within the meaning of section 10. If the Program as you received it, or any part of it, contains a notice stating that it is governed by this License along with a term that is a further restriction, you may remove that term. If a license document contains a further restriction but permits relicensing or conveying under this License, you may add to a covered work material governed by the terms of that license document, provided that the further restriction does not survive such relicensing or conveying.

If you add terms to a covered work in accord with this section, you must place, in the relevant source files, a statement of the additional terms that apply to those files, or a notice indicating where to find the applicable terms.

Additional terms, permissive or non-permissive, may be stated in the form of a separately written license, or stated as exceptions; the above requirements apply either way. 8. Termination.

You may not propagate or modify a covered work except as expressly provided under this License. Any attempt otherwise to propagate or modify it is void, and will automatically terminate your rights under this License (including any patent licenses granted under the third paragraph of section 11).

However, if you cease all violation of this License, then your license from a particular copyright holder is reinstated (a) provisionally, unless and until the copyright holder explicitly and finally terminates

your license, and (b) permanently, if the copyright holder fails to notify you of the violation by some reasonable means prior to 60 days after the cessation.

Moreover, your license from a particular copyright holder is reinstated permanently if the copyright holder notifies you of the violation by some reasonable means, this is the first time you have received notice of violation of this License (for any work) from that copyright holder, and you cure the violation prior to 30 days after your receipt of the notice.

Termination of your rights under this section does not terminate the licenses of parties who have received copies or rights from you under this License. If your rights have been terminated and not permanently reinstated, you do not qualify to receive new licenses for the same material under section 10. 9. Acceptance Not Required for Having Copies.

You are not required to accept this License in order to receive or run a copy of the Program. Ancillary propagation of a covered work occurring solely as a consequence of using peer-to-peer transmission to receive a copy likewise does not require acceptance. However, nothing other than this License grants you permission to propagate or modify any covered work. These actions infringe copyright if you do not accept this License. Therefore, by modifying or propagating a covered work, you indicate your acceptance of this License to do so. 10. Automatic Licensing of Downstream Recipients.

Each time you convey a covered work, the recipient automatically receives a license from the original licensors, to run, modify and propagate that work, subject to this License. You are not responsible for enforcing compliance by third parties with this License.

An "entity transaction" is a transaction transferring control of an organization, or substantially all assets of one, or subdividing an organization, or merging organizations. If propagation of a covered work results from an entity transaction, each party to that transaction who receives a copy of the work also receives whatever licenses to the work the party's predecessor in interest had or could give under the previous paragraph, plus a right to possession of the Corresponding Source of the work from the predecessor in interest, if the predecessor has it or can get it with reasonable efforts.

You may not impose any further restrictions on the exercise of the rights granted or affirmed under this License. For example, you may not impose a license fee, royalty, or other charge for exercise of rights granted under this License, and you may not initiate litigation (including a cross-claim or counterclaim in a lawsuit) alleging that any patent claim is infringed by making, using, selling, offering for sale, or importing the Program or any portion of it. 11. Patents.

A "contributor" is a copyright holder who authorizes use under this License of the Program or a work on which the Program is based. The work thus licensed is called the contributor's "contributor version".

A contributor's "essential patent claims" are all patent claims owned or controlled by the contributor, whether already acquired or hereafter acquired, that would be infringed by some manner, permitted by this License, of making, using, or selling its contributor version, but do not include claims that would be infringed only as a consequence of further modification of the contributor version. For purposes of this definition, "control" includes the right to grant patent sublicenses in a manner consistent with the requirements of this License.

Each contributor grants you a non-exclusive, worldwide, royalty-free patent license under the contributor's essential patent claims, to make, use, sell, offer for sale, import and otherwise run, modify and propagate the contents of its contributor version.

In the following three paragraphs, a "patent license" is any express agreement or commitment, however denominated, not to enforce a patent (such as an express permission to practice a patent or covenant not to sue for patent infringement). To "grant" such a patent license to a party means to make such an agreement or commitment not to enforce a patent against the party.

If you convey a covered work, knowingly relying on a patent license, and the Corresponding Source of the work is not available for anyone to copy, free of charge and under the terms of this License, through a publicly available network server or other readily accessible means, then you must either (1) cause the Corresponding Source to be so available, or (2) arrange to deprive yourself of the benefit of the patent license for this particular work, or (3) arrange, in a manner consistent with the requirements of this License, to extend the patent license to downstream recipients. "Knowingly relying" means you have actual knowledge that, but for the patent license, your conveying the covered work in a country, or your recipient's use of the covered work in a country, would infringe one or more identifiable patents in that country that you have reason to believe are valid.

If, pursuant to or in connection with a single transaction or arrangement, you convey, or propagate by procuring conveyance of, a covered work, and grant a patent license to some of the parties receiving the covered work authorizing them to use, propagate, modify or convey a specific copy of the covered work, then the patent license you grant is automatically extended to all recipients of the covered work and works based on it.

A patent license is "discriminatory" if it does not include within the scope of its coverage, prohibits the exercise of, or is conditioned on the non-exercise of one or more of the rights that are specifically granted under this License. You may not convey a covered work if you are a party to an arrangement with a third party that is in the business of distributing software, under which you make payment to the third party based on the extent of your activity of conveying the work, and under which the third party grants, to any of the parties who would receive the covered work from you, a discriminatory patent license (a) in connection with copies of the covered work conveyed by you (or copies made from those copies), or (b) primarily for and in connection with specific products or compilations that contain the covered work, unless you entered into that arrangement, or that patent license was granted, prior to 28 March 2007.

Nothing in this License shall be construed as excluding or limiting any implied license or other defenses to infringement that may otherwise be available to you under applicable patent law. 12. No Surrender of Others' Freedom.

If conditions are imposed on you (whether by court order, agreement or otherwise) that contradict the conditions of this License, they do not excuse you from the conditions of this License. If you cannot convey a covered work so as to satisfy simultaneously your obligations under this License and any other pertinent obligations, then as a consequence you may not convey it at all. For example, if you agree to terms that obligate you to collect a royalty for further conveying from those to whom you convey the Program, the only way you could satisfy

both those terms and this License would be to refrain entirely from conveying the Program. 13. Use with the GNU Affero General Public License.

Notwithstanding any other provision of this License, you have permission to link or combine any covered work with a work licensed under version 3 of the GNU Affero General Public License into a single combined work, and to convey the resulting work. The terms of this License will continue to apply to the part which is the covered work, but the special requirements of the GNU Affero General Public License, section 13, concerning interaction through a network will apply to the combination as such. 14. Revised Versions of this License.

The Free Software Foundation may publish revised and/or new versions of the GNU General Public License from time to time. Such new versions will be similar in spirit to the present version, but may differ in detail to address new problems or concerns.

Each version is given a distinguishing version number. If the Program specifies that a certain numbered version of the GNU General Public License "or any later version" applies to it, you have the option of following the terms and conditions either of that numbered version or of any later version published by the Free Software Foundation. If the Program does not specify a version number of the GNU General Public License, you may choose any version ever published by the Free Software Foundation.

If the Program specifies that a proxy can decide which future versions of the GNU General Public License can be used, that proxy's public statement of acceptance of a version permanently authorizes you to choose that version for the Program.

11.2 GNU Free Documentation License

Version 1.3, 3 November 2008

Copyright © 2000, 2001, 2002, 2007, 2008 Free Software Foundation, Inc. <<http://fsf.org/>>

Everyone is permitted to copy and distribute verbatim copies of this license document, but changing it is not allowed. 0. PREAMBLE

The purpose of this License is to make a manual, textbook, or other functional and useful document "free" in the sense of freedom: to assure everyone the effective freedom to copy and redistribute it, with or without modifying it, either commercially or noncommercially. Secondly, this License preserves for the author and publisher a way to get credit for their work, while not being considered responsible for modifications made by others.

This License is a kind of "copyleft", which means that derivative works of the document must themselves be free in the same sense. It complements the GNU General Public License, which is a copyleft license designed for free software.

We have designed this License in order to use it for manuals for free software, because free software needs free documentation: a free program should come with manuals providing the same freedoms that the software does. But this License is not limited to software manuals; it can be used for any textual work, regardless of subject matter or whether it is published as a printed book. We recommend this License principally for works whose purpose is instruction or reference. 1. APPLICABILITY AND DEFINITIONS

This License applies to any manual or other work, in any medium, that contains a notice placed by the copyright holder saying it can be distributed under the terms of this License. Such a notice grants a world-wide, royalty-free license, unlimited in duration, to use that work under the conditions stated herein. The "Document", below, refers to any such manual or work. Any member of the public is a licensee, and is addressed as "you". You accept the license if you copy, modify or distribute the work in a way requiring permission under copyright law.

A "Modified Version" of the Document means any work containing the Document or a portion of it, either copied verbatim, or with modifications and/or translated into another language.

A "Secondary Section" is a named appendix or a front-matter section of the Document that deals exclusively with the relationship of the publishers or authors of the Document to the Document's overall subject (or to related matters) and contains nothing that could fall directly within that overall subject. (Thus, if the Document is in part a textbook of mathematics, a Secondary Section may not explain any mathematics.) The relationship could be a matter of historical connection with the subject or with related matters, or of legal, commercial, philosophical, ethical or political position regarding them.

The "Invariant Sections" are certain Secondary Sections whose titles are designated, as being those of Invariant Sections, in the notice that says that the Document is released under this License. If a section does not fit the above definition of Secondary then it is not allowed to be designated as Invariant. The Document may contain zero Invariant Sections. If the Document does not identify any Invariant Sections then there are none.

The "Cover Texts" are certain short passages of text that are listed, as Front-Cover Texts or Back-Cover Texts, in the notice that says that the Document is released under this License. A Front-Cover Text may be at most 5 words, and a Back-Cover Text may be at most 25 words.

A "Transparent" copy of the Document means a machine-readable copy, represented in a format whose specification is available to the general public, that is suitable for revising the document straightforwardly with generic text editors or (for images composed of pixels) generic paint programs or (for drawings) some widely available drawing editor, and that is suitable for input to text formatters or for automatic translation to a variety of formats suitable for input to text formatters. A copy made in an otherwise Transparent file format whose markup, or absence of markup, has been arranged to thwart or discourage subsequent modification by readers is not Transparent. An image format is not Transparent if used for any substantial amount of text. A copy that is not "Transparent" is called "Opaque".

Examples of suitable formats for Transparent copies include plain ASCII without markup, Texinfo input format, LaTeX input format, SGML or XML using a publicly available DTD, and standard-conforming simple HTML, PostScript or PDF designed for human modification. Examples of transparent image formats include PNG, XCF and JPG. Opaque formats include proprietary formats that can be read and edited only by proprietary word processors, SGML or XML for which the DTD and/or processing tools are not generally available, and the machine-generated HTML, PostScript or PDF produced by some word processors for output purposes only.

The "Title Page" means, for a printed book, the title page itself, plus such following pages as are needed to hold, legibly, the material this License requires to appear in the title page. For works in formats which do not have any title page as such, "Title Page" means the text near the most prominent appearance of the work's title, preceding the beginning of the body of the text.

The "publisher" means any person or entity that distributes copies of the Document to the public.

A section "Entitled XYZ" means a named subunit of the Document whose title either is precisely XYZ or contains XYZ in parentheses

Later license versions may give you additional or different permissions. However, no additional obligations are imposed on any author or copyright holder as a result of your choosing to follow a later version. 15. Disclaimer of Warranty.

THERE IS NO WARRANTY FOR THE PROGRAM, TO THE EXTENT PERMITTED BY APPLICABLE LAW. EXCEPT WHEN OTHERWISE STATED IN WRITING THE COPYRIGHT HOLDERS AND/OR OTHER PARTIES PROVIDE THE PROGRAM "AS IS" WITHOUT WARRANTY OF ANY KIND, EITHER EXPRESSED OR IMPLIED, INCLUDING, BUT NOT LIMITED TO, THE IMPLIED WARRANTIES OF MERCHANTABILITY AND FITNESS FOR A PARTICULAR PURPOSE. THE ENTIRE RISK AS TO THE QUALITY AND PERFORMANCE OF THE PROGRAM IS WITH YOU. SHOULD THE PROGRAM PROVE DEFECTIVE, YOU ASSUME THE COST OF ALL NECESSARY SERVICING, REPAIR OR CORRECTION. 16. Limitation of Liability.

IN NO EVENT UNLESS REQUIRED BY APPLICABLE LAW OR AGREED TO IN WRITING WILL ANY COPYRIGHT HOLDER, OR ANY OTHER PARTY WHO MODIFIES AND/OR CONVEYS THE PROGRAM AS PERMITTED ABOVE, BE LIABLE TO YOU FOR DAMAGES, INCLUDING ANY GENERAL, SPECIAL, INCIDENTAL OR CONSEQUENTIAL DAMAGES ARISING OUT OF THE USE OR INABILITY TO USE THE PROGRAM (INCLUDING BUT NOT LIMITED TO LOSS OF DATA OR DATA BEING RENDERED INACCURATE OR LOSSES SUSTAINED BY YOU OR THIRD PARTIES OR A FAILURE OF THE PROGRAM TO OPERATE WITH ANY OTHER PROGRAMS), EVEN IF SUCH HOLDER OR OTHER PARTY HAS BEEN ADVISED OF THE POSSIBILITY OF SUCH DAMAGES. 17. Interpretation of Sections 15 and 16.

following text that translates XYZ in another language. (Here XYZ stands for a specific section name mentioned below, such as "Acknowledgements", "Dedications", "Endorsements", or "History"). To "Preserve the Title" of such a section when you modify the Document means that it remains a section "Entitled XYZ" according to this definition.

The Document may include Warranty Disclaimers next to the notice which states that this License applies to the Document. These Warranty Disclaimers are considered to be included by reference in this License, but only as regards disclaiming warranties; any other implication that these Warranty Disclaimers may have is void and has no effect on the meaning of this License. 2. VERBATIM COPYING

You may copy and distribute the Document in any medium, either commercially or noncommercially, provided that this License, the copyright notices, and the license notice saying this License applies to the Document are reproduced in all copies, and that you add no other conditions whatsoever to those of this License. You may not use technical measures to obstruct or control the reading or further copying of the copies you make or distribute. However, you may accept compensation in exchange for copies. If you distribute a large enough number of copies you must also follow the conditions in section 3.

You may also lend copies, under the same conditions stated above, and you may publicly display copies. 3. COPYING IN QUANTITY

If you publish printed copies (or copies in media that commonly have printed covers) of the Document, numbering more than 100, and the Document's license notice requires Cover Texts, you must enclose the copies in covers that carry, clearly and legibly, all these Cover Texts: Front-Cover Texts on the front cover, and Back-Cover Texts on the back cover. Both covers must also clearly and legibly identify you as the publisher of these copies. The front cover must present the full title with all words of the title equally prominent and visible. You may add other material on the covers in addition. Copying with changes limited to the covers, as long as they preserve the title of the Document and satisfy these conditions, can be treated as verbatim copying in other respects.

If the required texts for either cover are too voluminous to fit legibly, you should put the first one listed (as many as fit reasonably) on the actual cover, and continue the rest onto adjacent pages.

If you publish or distribute Opaque copies of the Document numbering more than 100, you must either include a machine-readable Transparent copy along with each Opaque copy, or state in or with each Opaque copy a computer-network location from which the general network-using public has access to download using public-standard network protocols a complete Transparent copy of the Document, free of added material. If you use the latter option, you must take reasonably prudent steps, when you begin distribution of Opaque copies in quantity, to ensure that this Transparent copy will remain thus accessible at the stated location until at least one year after the last time you distribute an Opaque copy (directly or through your agents or retailers) of that edition to the public.

It is requested, but not required, that you contact the authors of the Document well before redistributing any large number of copies, to give them a chance to provide you with an updated version of the Document. 4. MODIFICATIONS

You may copy and distribute a Modified Version of the Document under the conditions of section 2 above, provided that you release the Modified Version under precisely this License, with the Modified Version filling the role of the Document, this licensing distribution and modification of the Modified Version to whoever possesses a copy of it. In addition, you must do these things in the Modified Version:

* A. Use in the Title Page (and on the covers, if any) a title distinct from that of the Document, and from those of previous versions (which should, if there were any, be listed in the History section of the Document). You may use the same title as a previous version if the original publisher of that version gives permission. * B. List on the Title Page, as authors, one or more persons or entities responsible for authorship of the modifications in the Modified Version, together with at least five of the principal authors of the Document (all of its principal authors, if it has fewer than five), unless they release you from this requirement. * C. State on the Title page the name of the publisher of the Modified Version, as the publisher. * D. Preserve all the copyright notices of the Document. * E. Add an appropriate copyright notice for your modifications adjacent to the other copyright notices. * F. Include, immediately after the copyright notices, a license notice giving the public permission to use the Modified Version under the terms of this license, in the form shown below. * G. Preserve in the license notice the full lists of Invariant Sections and required Cover Texts given in the Document's license notice. * H. Include an unaltered copy of this License. * I. Preserve the section entitled "History", Preserve its Title, and add to it an item stating at least the title, year, new authors, and publisher of the Modified Version as given on the Title Page. If there is no section entitled "History" in the Document, create one stating the title, year, authors, and publisher of the Document as given on its Title Page, then add an item describing the Modified Version as stated in the previous section. * J. Preserve the network location, if any, given in the Document for public access to a Transparent copy of the Document, and likewise the network locations given in the Document for previous versions it was based on. These may be placed in the "History" section. You may omit a network location for work that was published at least four years before the Document itself, or if the original publisher of the version it refers to gives permission. * K. For a section entitled "Acknowledgements" or "Dedications", Preserve the Title of the section, and preserve in the section all the substance and tone of each of the contributor acknowledgements and/or dedications given therein. * L. Preserve all the Invariant Sections of the Document, unaltered in their text and

If the disclaimer of warranty and limitation of liability provided above cannot be given local legal effect according to their terms, reviewing courts shall apply local law that most closely approximates an absolute waiver of all civil liability in connection with the Program, unless a warranty or assumption of liability accompanies a copy of the Program in return for a fee.

END OF TERMS AND CONDITIONS How to Apply These Terms to Your New Programs

If you develop a new program, and you want it to be of the greatest possible use to the public, the best way to achieve this is to make it free software which everyone can redistribute and change under these terms.

To do so, attach the following notices to the program. It is safest to attach them to the start of each source file to most effectively state the exclusion of warranty; and each file should have at least the "copyright" line and a pointer to where the full notice is found.

<one line to give the program's name and a brief idea of what it does.>
Copyright (C) <year> <name of author>

This program is free software: you can redistribute it and/or modify it under the terms of the GNU General Public License as published by the Free Software Foundation, either version 3 of the License, or (at your option) any later version.

This program is distributed in the hope that it will be useful, but WITHOUT ANY WARRANTY; without even the implied warranty of MERCHANTABILITY or FITNESS FOR A PARTICULAR PURPOSE. See the GNU General Public License for more details.

in their titles. Section numbers or the equivalent are not considered part of the section titles. * M. Delete any section Entitled "Endorsements". Such a section may not be included in the Modified Version. * N. Do not retile any existing section to be Entitled "Endorsements" or to conflict in title with any Invariant Section. * O. Preserve any Warranty Disclaimers.

If the Modified Version includes new front-matter sections or appendices that qualify as Secondary Sections and contain no material copied from the Document, you may at your option designate some or all of these sections as invariant. To do this, add their titles to the list of Invariant Sections in the Modified Version's license notice. These titles must be distinct from any other section titles.

You may add a section Entitled "Endorsements", provided it contains nothing but endorsements of your Modified Version by various parties—for example, statements of peer review or of the text has been approved by an organization as the authoritative definition of a standard.

You may add a passage of up to five words as a Front-Cover Text, and a passage of up to 25 words as a Back-Cover Text, to the end of the list of Cover Texts in the Modified Version. Only one passage of Front-Cover Text and one of Back-Cover Text may be added (or through arrangements made by) any one entity. If the Document already includes a cover text for the same cover, previously added by you or by arrangement made by the same entity you are acting on behalf of, you may not add another; but you may replace the old one, on explicit permission from the previous publisher that added the old one.

The author(s) and publisher(s) of the Document do not by this License give permission to use their names for publicity for or to assert or imply endorsement of any Modified Version. 5. COMBINING DOCUMENTS

You may combine the Document with other documents released under this License, under the terms defined in section 4 above for modified versions, provided that you include in the combination all of the Invariant Sections of all of the original documents, unmodified, and list them all as Invariant Sections of your combined work in its license notice, and that you preserve all their Warranty Disclaimers.

The combined work need only contain one copy of this License, and multiple identical Invariant Sections may be replaced with a single copy. If there are multiple Invariant Sections with the same name but different contents, make the title of each such section unique by adding at the end of it, in parentheses, the name of the original author or publisher of that section if known, or else a unique number. Make the same adjustment to the section titles in the list of Invariant Sections in the license notice of the combined work.

In the combination, you must combine any sections Entitled "History" in the various original documents, forming one section Entitled "History"; likewise combine any sections Entitled "Acknowledgements", and any sections Entitled "Dedications". You must delete all sections Entitled "Endorsements". 6. COLLECTIONS OF DOCUMENTS

You may make a collection consisting of the Document and other documents released under this License, and replace the individual copies of this License in the various documents with a single copy that is included in the collection, provided that you follow the rules of this License for verbatim copying of each of the documents in all other respects.

You may extract a single document from such a collection, and distribute it individually under this License, provided you insert a copy of this License into the extracted document, and follow this License in all other respects regarding verbatim copying of that document. 7. AGGREGATION WITH INDEPENDENT WORKS

A compilation of the Document or its derivatives with other separate and independent documents or works, in or on a volume of a storage or distribution medium, is called an "aggregate" if the copyright resulting from the compilation is not used to limit the legal rights of the compilation's users beyond what the individual works permit. When the Document is included in an aggregate, this License does not apply to the other works in the aggregate which are not themselves derivative works of the Document.

If the Cover Text requirement of section 3 is applicable to these copies of the Document, then if the Document is less than one half of the entire aggregate, the Document's Cover Texts may be placed on covers that bracket the Document within the aggregate, or the electronic equivalent of covers if the Document is in electronic form. Otherwise they must appear on printed covers that bracket the whole aggregate. 8. TRANSLATION

Translation is considered a kind of modification, so you may distribute translations of the Document under the terms of section 4. Replacing Invariant Sections with translations requires special permission from their copyright holders, but you may include translations of some or all Invariant Sections in addition to the original versions of these Invariant Sections. You may include a translation of this License, and all the license notices in the Document, and any Warranty Disclaimers, provided that you also include the original English version of this License and the original versions of those notices and disclaimers. In case of a disagreement between the translation and the original version of this License or a notice or disclaimer, the original version will prevail.

If a section in the Document is Entitled "Acknowledgements", "Dedications", or "History", the requirement (section 4) to Preserve its Title

You should have received a copy of the GNU General Public License along with this program. If not, see <<http://www.gnu.org/licenses/>>.

Also add information on how to contact you by electronic and paper mail.

If the program does terminal interaction, make it output a short notice like this when it starts in an interactive mode:

<program> Copyright (C) <year> <name of author> This program comes with ABSOLUTELY NO WARRANTY; for details type 'show w'. This is free software, and you are welcome to redistribute it under certain conditions; type 'show c' for details.

The hypothetical commands 'show w' and 'show c' should show the appropriate parts of the General Public License. Of course, your program's commands might be different; for a GUI interface, you would use an "about box".

You should also get your employer (if you work as a programmer) or school, if any, to sign a "copyright disclaimer" for the program, if necessary. For more information on this, and how to apply and follow the GNU GPL, see <<http://www.gnu.org/licenses/>>.

The GNU General Public License does not permit incorporating your program into proprietary programs. If your program is a subroutine library, you may consider it more useful to permit linking proprietary applications with the library. If this is what you want to do, use the GNU Lesser General Public License instead of this License. But first, please read <<http://www.gnu.org/philosophy/why-not-lgpl.html>>.

(section 1) will typically require changing the actual title. 9. TERMINATION

You may not copy, modify, sublicense, or distribute the Document except as expressly provided under this License. Any attempt otherwise to copy, modify, sublicense, or distribute it is void, and will automatically terminate your rights under this License.

However, if you cease all violation of this License, then your license from a particular copyright holder is reinstated (a) provisionally, unless and until the copyright holder explicitly and finally terminates your license, and (b) permanently, if the copyright holder fails to notify you of the violation by some reasonable means prior to 60 days after the cessation.

Moreover, your license from a particular copyright holder is reinstated permanently if the copyright holder notifies you of the violation by some reasonable means, this is the first time you have received notice of violation of this License (for any work) from that copyright holder, and you cure the violation prior to 30 days after your receipt of the notice.

Termination of your rights under this section does not terminate the licenses of parties who have received copies or rights from you under this License. If your rights have been terminated and not permanently reinstated, receipt of a copy of some or all of the same material does not give you any rights to use it. 10. FUTURE REVISIONS OF THIS LICENSE

The Free Software Foundation may publish new, revised versions of the GNU Free Documentation License from time to time. Such new versions will be similar in spirit to the present version, but may differ in detail to address new problems or concerns. See <<http://www.gnu.org/copyleft/>>.

Each version of the License is given a distinguishing version number. If the Document specifies that a particular numbered version of this License "or any later version" applies to it, you have the option of following the terms and conditions either of that specified version or of any later version that has been published (not as a draft) by the Free Software Foundation. If the Document does not specify a version number of this License, you may choose any version ever published (not as a draft) by the Free Software Foundation. If the Document specifies that a proxy can decide which future versions of this License can be used, that proxy's public statement of acceptance of a version permanently authorizes you to choose that version for the Document. 11. RELICENSING

"Massive Multiauthor Collaboration Site" (or "MMC Site") means any World Wide Web server that publishes copyrightable works and also provides prominent facilities for anybody to edit those works. A public webkit that anybody can edit is an example of such a server. A "Massive Multiauthor Collaboration" (or "MMC") contained in the site means any set of copyrightable works thus published on the MMC site.

"CC-BY-SA" means the Creative Commons Attribution-Share Alike 3.0 license published by Creative Commons Corporation, a not-for-profit corporation with a principal place of business in San Francisco, California, as well as future copyleft versions of that license published by that same organization.

"Incorporate" means to publish or republish a Document, in whole or in part, as part of another Document.

An MMC is "eligible for relicensing" if it is licensed under this License, and if all works that were first published under this License somewhere other than this MMC, and subsequently incorporated in whole or in part into the MMC, (1) had no cover texts or invariant sections, and (2) were thus incorporated prior to November 1, 2008.

The operator of an MMC Site may republish an MMC contained in the site under CC-BY-SA on the same site at any time before August 1, 2009, provided the MMC is eligible for relicensing. ADDENDUM: How to use this License for your documents

To use this License in a document you have written, include a copy of the License in the document and put the following copyright and license notices just after the title page:

Copyright (C) YEAR YOUR NAME. Permission is granted to copy, distribute and/or modify this document under the terms of the GNU Free Documentation License, Version 1.3 or any later version published by the Free Software Foundation; with no Invariant Sections, no Front-Cover Texts, and no Back-Cover Texts. A copy of the License is included in the section entitled "GNU Free Documentation License".

If you have Invariant Sections, Front-Cover Texts and Back-Cover Texts, replace the "with ... Texts." line with this:

with the Invariant Sections being LIST THEIR TITLES, with the Front-Cover Texts being LIST, and with the Back-Cover Texts being LIST.

If you have Invariant Sections without Cover Texts, or some other combination of the three, merge those two alternatives to suit the situation.

If your document contains nontrivial examples of program code, we recommend releasing these examples in parallel under your choice of free software license, such as the GNU General Public License, to permit their use in free software.

11.3 GNU Lesser General Public License

GNU LESSER GENERAL PUBLIC LICENSE

Version 3, 29 June 2007

Copyright © 2007 Free Software Foundation, Inc. <<http://fsf.org/>>

Everyone is permitted to copy and distribute verbatim copies of this license document, but changing it is not allowed.

This version of the GNU Lesser General Public License incorporates the terms and conditions of version 3 of the GNU General Public License, supplemented by the additional permissions listed below.

0. Additional Definitions.

As used herein, “this License” refers to version 3 of the GNU Lesser General Public License, and the “GNU GPL” refers to version 3 of the GNU General Public License.

“The Library” refers to a covered work governed by this License, other than an Application or a Combined Work as defined below.

An “Application” is any work that makes use of an interface provided by the Library, but which is not otherwise based on the Library. Defining a subclass of a class defined by the Library is deemed a mode of using an interface provided by the Library.

A “Combined Work” is a work produced by combining or linking an Application with the Library. The particular version of the Library with which the Combined Work was made is also called the “Linked Version”.

The “Minimal Corresponding Source” for a Combined Work means the Corresponding Source for the Combined Work, excluding any source code for portions of the Combined Work that, considered in isolation, are based on the Application, and not on the Linked Version.

The “Corresponding Application Code” for a Combined Work means the object code and/or source code for the Application, including any data and utility programs needed for reproducing the Combined Work from the Application, but excluding the System Libraries of the Combined Work.

1. Exception to Section 3 of the GNU GPL.

You may convey a covered work under sections 3 and 4 of this License without being bound by section 3 of the GNU GPL.

2. Conveying Modified Versions.

If you modify a copy of the Library, and, in your modifications, a facility refers to a function or data to be supplied by an Application that uses the facility (other than as an argument passed when the facility is invoked), then you may convey a copy of the modified version:

* a) under this License, provided that you make a good faith effort to ensure that, in the event an Application does not supply the function or data, the facility still operates, and performs whatever part of its purpose remains meaningful, or

* b) under the GNU GPL, with none of the additional permissions of this License applicable to that copy.

3. Object Code Incorporating Material from Library Header Files.

The object code form of an Application may incorporate material from a header file that is part of the Library. You may convey such object code under terms of your choice, provided that, if the incorporated material is not limited to numerical parameters, data structure layouts and accessors, or small macros, inline functions and templates (ten or fewer lines in length), you do both of the following:

* a) Give prominent notice with each copy of the object code that the Library is used in it and that the Library and its use are covered by this License.

* b) Accompany the object code with a copy of the GNU GPL and this license document.

4. Combined Works.

You may convey a Combined Work under terms of your choice that, taken together, effectively do not restrict modification of the portions of the Library contained in the Combined Work and reverse engineering for debugging such modifications, if you also do each of the following:

* a) Give prominent notice with each copy of the Combined Work that the Library is used in it and that the Library and its use are covered by this License.

* b) Accompany the Combined Work with a copy of the GNU GPL and this license document.

* c) For a Combined Work that displays copyright notices during execution, include the copyright notice for the Library among these notices, as well as a reference directing the user to the copies of the GNU GPL and this license document.

* d) Do one of the following:

- o 0) Convey the Minimal Corresponding Source under the terms of this License, and the Corresponding Application Code in a form suitable for, and under terms that permit, the user to recombine or relink the Application with a modified version of the Linked Version to produce a modified Combined Work, in the manner specified by section 6 of the GNU GPL for conveying Corresponding Source.
- o 1) Use a suitable shared library mechanism for linking with the Library. A suitable mechanism is one that (a) uses at run time a copy of the Library already present on the user’s computer system, and (b) will operate properly with a modified version of the Library that is interface-compatible with the Linked Version.
- * e) Provide Installation Information, but only if you would otherwise be required to provide such information under section 6 of the GNU GPL, and only to the extent that such information is necessary to install and execute a modified version of the Combined Work produced by recombining or relinking the Application with a modified version of the Linked Version. (If you use option 4d0, you must provide the Installation Information in the manner specified by section 6 of the GNU GPL for conveying Corresponding Source.)

5. Combined Libraries.

You may place library facilities that are a work based on the Library side by side in a single library together with other library facilities that are not Applications and are not covered by this License, and convey such a combined library under terms of your choice, if you do both of the following:

* a) Accompany the combined library with a copy of the same work based on the Library, uncombined with any other library facilities, conveyed under the terms of this License.

* b) Give prominent notice with the combined library that part of it is a work based on the Library, and explaining where to find the accompanying uncombined form of the same work.

6. Revised Versions of the GNU Lesser General Public License.

The Free Software Foundation may publish revised and/or new versions of the GNU Lesser General Public License from time to time. Such new versions will be similar in spirit to the present version, but may differ in detail to address new problems or concerns.

Each version is given a distinguishing version number. If the Library as you received it specifies that a certain numbered version of the GNU Lesser General Public License “or any later version” applies to it, you have the option of following the terms and conditions either of that published version or of any later version published by the Free Software Foundation. If the Library as you received it does not specify a version number of the GNU Lesser General Public License, you may choose any version of the GNU Lesser General Public License ever published by the Free Software Foundation.

If the Library as you received it specifies that a proxy can decide whether future versions of the GNU Lesser General Public License shall apply, that proxy’s public statement of acceptance of any version is permanent authorization for you to choose that version for the Library.